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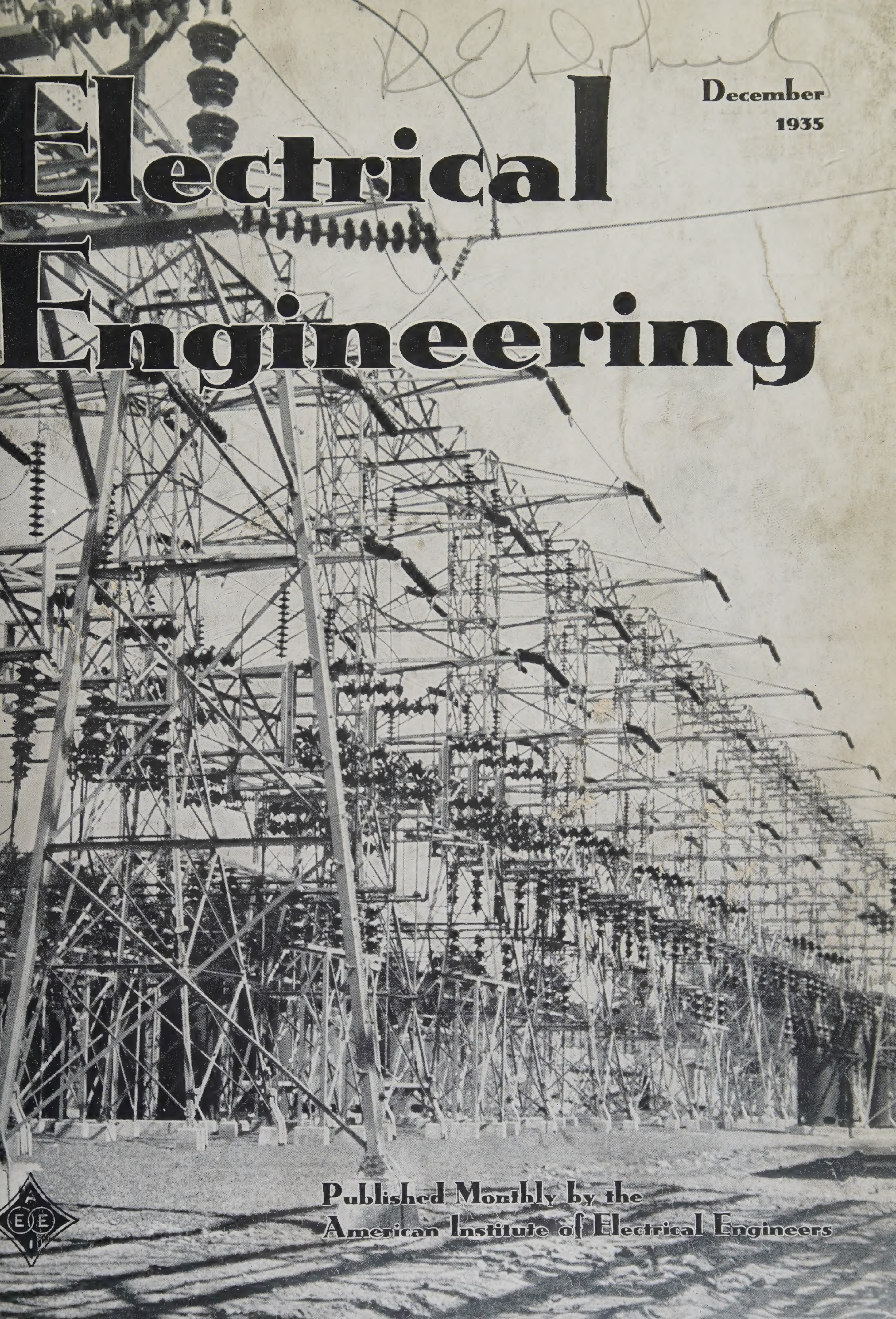

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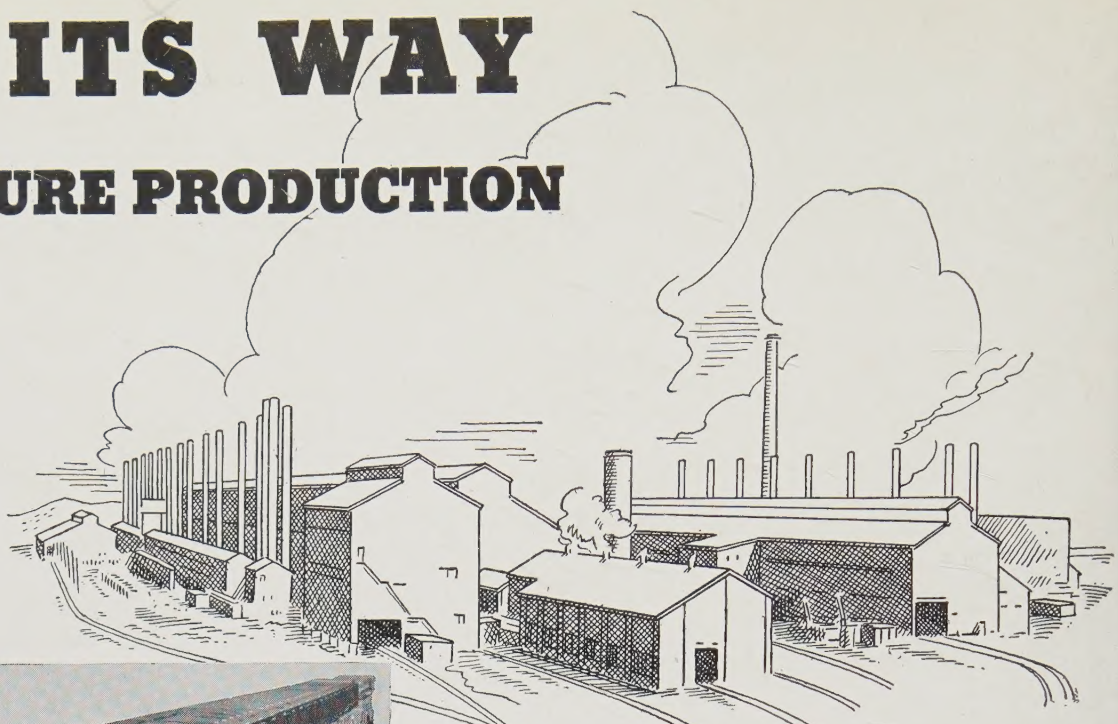

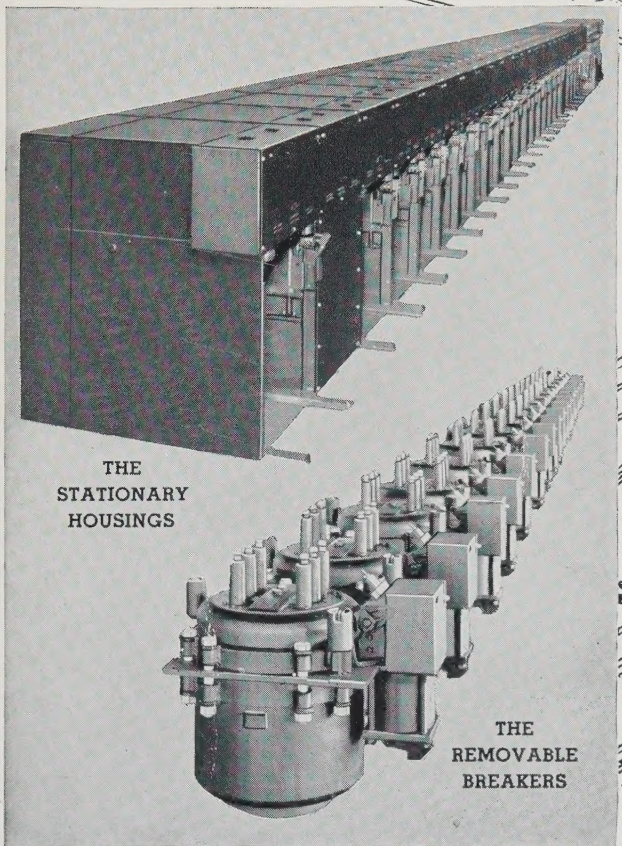

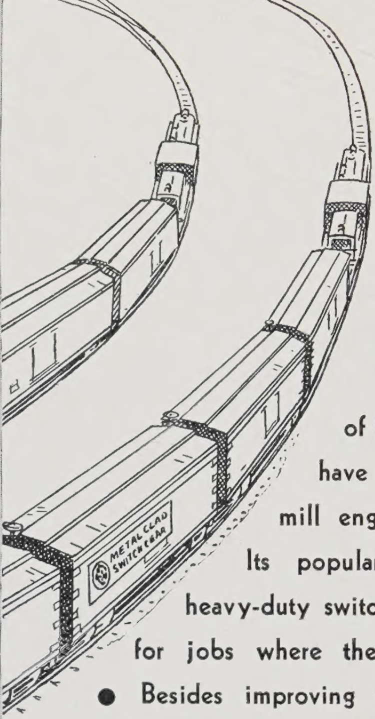

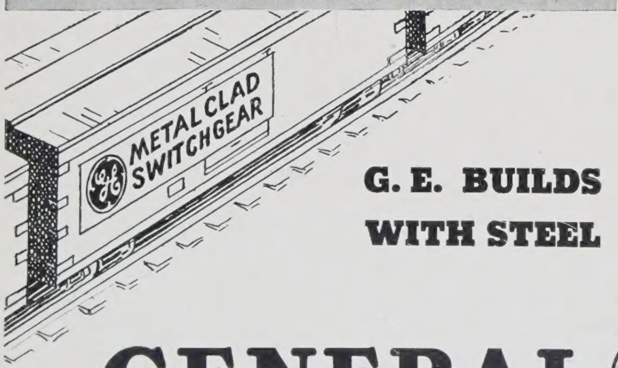

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Front Cover

A view of the Pleasant Valley (N. Y.) substation of the New York Power and Light Company where the Niagara-Hudson and New York Edison transmission systems are joined together. Photo by F. A. Lewis (A'31)

Special Articles

A.I.E.E. Papers

—Turn to next page

1935 Index . . . . page 1426

On the 19 pages beginning with page 1426 of this issue is published the annual reference index, listing some 2,400 entries, covering all text material published in ELECTRICAL ENGINEERING during 1935. Special information regarding the index is given on page 1426.

In This Issue—

MAGNETIC MATERIALS are featured in 3 papers in this issue. One summarizes the results of extensive research on magnetic alloys of iron, nickel, and cobalt (*pages 1292–9*); a second discusses different grades of silicon steel and other magnetic materials and their application to communication equipment (*pages 1348–53*); a third outlines recent improvements in communication transformers, which have been made possible largely by improved core materials (*pages 1367–73*). A fourth paper on this same general subject contains a bibliography of 211 items on research in magnetics done during the years 1933–34 (*pages 1354–9*).

LIGHTNING protection of distribution systems is treated in 2 papers in this issue. One paper summarizes the experiences of one large company in rather severe lightning territory where the improvement in protection expected from interconnecting the arrester grounds and the secondary neutrals was not as great as expected (*pages 1400–05*). The other paper reports the results of measurements of lightning currents in arresters on 4 distribution systems in different parts of the United States; a maximum current of 17,000 amperes was recorded (*pages 1395–9*).

ELECTROCHEMICAL and electrometallurgical industries have developed so rapidly in recent years that it has been impossible to disseminate the knowledge which has been gained. Some notes on the engineering development of these industries, particularly in France, have been prepared by a French engineer. Descriptions of new equipment for producing calcium carbide and aluminum electrically are included (*pages 1320–31*).

SALIENT pole synchronous machines are discussed in 2 papers in this issue: one outlines methods of determining load losses and presents the results of calculations made by those methods (*pages 1332–40*); the other presents the results of pulling-into-step solutions made on the new large mechanical integraph at the University of Pennsylvania (*pages 1385–95*).

RECENT research in the field of dielectrics, particularly on materials and methods used at high voltages, was reported in one paper presented at the recent meeting of National Research Council's committee on electrical insulation (*pages 1288–91*). A news report summarizes the principal subjects discussed at this meeting (*page 1416*).

THE danger of self-excitation of a Scherbius machine used in a variable ratio frequency converter for inherently constant power transfer has been studied, and means of preventing self-excitation during normal operation have been indicated (*pages 1359–66*).

NOISE frequency induction on telephone lines resulting from exposure to electric power lines has been subject to considerable investigation by both communication and power system engineers. The results of some recent studies are reported in this issue (*pages 1307–15*).

THE MKS (meter-kilogram-second) system of units was adopted by the International Electrotechnical Commission at its plenary meeting of June 1935. Not since 1881 has a decision of similar international significance been made (*pages 1373–84*).

IN ADDITION to the many technical papers and discussions thereon which were part of the recent meeting of the A.I.E.E. Great Lakes District at Purdue University, a noteworthy feature was the attention given to students (*pages 1410–12*).

MASS TRANSIT by means of continuously moving electrically operated platforms is said to have some advantages over other means of rapid transit for the congested sections of large cities (*pages 1340–7*).

THE technical program for the annual winter convention of the A.I.E.E. to be held in New York, N. Y., January 28–31, 1936, has been announced (*pages 1408–09*).

A VOLT-TIME curve for solid insulation, presented in this issue, considerably extends the range of information available on this subject (*pages 1300–01*).

METHODS of segregating the losses in single phase induction and capacitor motors are outlined in this issue (*pages 1302–06*).

1936 TRANSACTIONS Final notice!

The A.I.E.E. TRANSACTIONS for 1936 will be produced only for those having subscription cards on file at A.I.E.E. headquarters not later than Friday, December 20, 1935. Present production methods require determination, in advance of the printing of the January 1936 issue of ELECTRICAL ENGINEERING of the exact number of TRANSACTIONS volumes to be provided for. For the convenience of members desiring to maintain in this permanent form a file of A.I.E.E. papers and discussions, important additional information and a convenient order blank are provided on page 10 of the advertising section of ~~this~~ the November 1935 issue.

Friendship and the Engineer

—*A Message From the President*

IN these trying times of stress and economic instability, engineers, like the rest of the business world, are trying to keep the ships of enterprise off the rocks of economic and financial disaster, and are exerting heroic efforts to keep the flag of hope flying bravely in the storm. Their associates and fellow workers can help bear the burden of worry and responsibility by their sympathy and loyalty, and by simply offering their friendship in the constant courageous battle.

Recently I had occasion to interview a man who is the executive head of a large corporation. In the course of our conversation, he remarked, "Friendship in business means nothing to me; it is only the cold hard facts that count." I feel sorry for such a man. Do you know that after many years of considering only cold hard facts, business finally has awakened to the idea that human interest is the greatest force in industry?

The one thing that counteracts discord is harmony, and we approach this in business along the path of friendship. The man who is on friendly terms with his associates will carry on his business or activity far better than the one who is actuated only by the colder sentiments. We try to believe that we think and act independently, but as a rule we are greatly influenced by our contacts with others, particularly by those of our business associates who are our friends.

And so it is with us in our Institute life. The benefits which an engineer derives from his membership in the Institute come primarily from his taking advantage of the opportunities presented for establishing and extending intimate relations and mutual understandings with others of his profession. The development of a true spirit of helpfulness in the free exchange of ideas contributes immensely to individual advancement. But, beyond this, lies the even greater personal satisfaction of association, good-fellowship, and friendliness.

The season of the year when friendliness and good-fellowship are in greatest evidence is fast approaching. At this time our thoughts are inclined to dwell more on others—members of our families, friends, associates, and those who are in need. We try to foster good feeling and draw upon our many resources to extend a helping hand in replacing sorrow and sadness with joy and cheerfulness.

However, many of us in our every day lives are far too susceptible to the material things which play a part in our efforts—sometimes a large part and sometimes small. While material things constitute the basic element of our business activity and are fundamental to our physical well-being, they really make up the smaller portion of the sum of our contentment.

The greatest joy and satisfaction are derived from the little things in life—those things that, in general, are without cost to us and can be procured without difficulty—our friends, who think and speak kindly of us, interesting books, cheerful words, friendly smiles, or acts of kindness. They usually take us by surprise.

Everyone has heard the familiar legend of the man who searched all over the world for diamonds, and, finding none, returned home in disappointment. Then to his delight, he discovered "acres of diamonds" on his own land which he had neglected to search before starting on his quest.

It is the same with many of us. We are possessed with an insatiable desire for the unattainable. We strive to accomplish some material purpose because of the satisfaction, the feeling of success that accompanies victory. While it is true that patience, perseverance, and aggressiveness are commendable and essential to progress and individual advancement, they often cause us to miss the myriad little things surrounding us that really make living enjoyable and worth-while.

As the holiday season approaches, it brings with it a spirit of happiness and rejoicing. Christmas reminds us of many happy events—forgotten in the daily struggle to keep up with the times—the old homestead, the merry voices, and smiling faces. The most minute and trivial circumstances connected with those joyful meetings crowd upon our minds at each recurrence of the season as if the last had been but yesterday.

Christmas can win us back to the realization of the importance of friendship in our daily lives. Injecting its spirit into our every endeavor will return its blessings a thousandfold.

With this message I extend to all the members of the American Institute of Electrical Engineers my friendly and sincere wish for happiness this Christmas season and the coming year.

E. B. Meyer

Recent Progress in Dielectric Research

Research in the several fields intimately involved in improving the formulation and application of electrical insulating materials is continuing with unrelenting efforts. The following summary of some of the current (1934–35) results indicates something of the scope and significance of this work.

By
JOHN B. WHITEHEAD
FELLOW A.I.E.E.

The Johns Hopkins University, Baltimore, Md.

RESEARCH and experimental development have produced several interesting advances during the past year. Direct study of insulating materials has resulted in new combinations for special types of service and in noteworthy new extensions in the high voltage field. In the field of basic research, as usual the effort has been toward better experimental control, more intimate knowledge, and more clearly cut theories in all classes of dielectric materials and phenomena. Liquids have received the greatest attention because of their wide ranges of inherent properties, their susceptibility to control, and the great interest in them from the standpoints of both theory and application as insulators.

Liquids

Research in the field of liquids has covered an especially wide range of study of dipolar properties. Much of this is in the direction of correlation with other knowledge of molecular structure and combination arising in chemical research. Such work is full of ultimate promise of new knowledge bearing upon the insulating properties of materials. Up to the present, however, available results from the standpoint of insulation are limited to such matters as dielectric constant and loss at high frequencies. All such work is in the high frequency range where the dipolar elements of loss, phase difference, and dielectric constant are clearly established. Interesting data of this type for insulating oils are present in papers by Beck,[1] Rieche,[33] and Sommerman,[45] all of which indicate that molecular dipolar behavior at normal temperatures is limited to the high frequency range. Further, it generally is unaffected by increases in low frequency losses, and there may be several different polar elements in the same liquid. In certain cases low frequency losses which seem to have polar characteristics are ascribed to polarized aggregates of much larger than molecular dimensions. Nowhere in all this work is there as yet a possibility of a quantitative check of Debye's theory in the matters of loss and phase difference, owing to the as yet imperfect knowledge of the phenomena of internal friction and dissociation.

Conduction in insulating liquids has been studied theoretically by Sammer[35] who extends to the case of liquids Schumann's theory for crystals. Expressions for d-c and a-c behavior are derived as based upon ionic mobilities, and certain qualitative agreements with the results of experiment are obtained. Schumann,[40] in a theoretical analysis, shows that the motions in liquids of layers of different ionic densities or space charge may result in one or more maxima of current as observed by Whitehead and his coworkers. Further interesting experiments in this direction are reported by Hofmann[20] who, using the "schlieren" method and a movie camera, photographs the motion of the space charge and measures its velocity. He finds ionic mobilities up to 10^{-4} cm/sec/volt/cm, confirming the value announced by Whitehead and Marvin[53] several years ago. The mobilities of the ions in ordinary electrolytic solutions are in this range and it is not yet clear how this high value can be reached in the more viscous insulating liquids. Hofmann,[20] in explanation of various features of his results, invokes the attraction of polar molecules to a free ion and the motion of the resulting larger aggregate. Gillies[14] reports observations on conduction at high field strength, confirming the theory that ionization by collision is the basic factor. The electrical purification of liquids by application of continuous voltage has been studied by Whitehead and Shevki[54] who show the close relationship between short time conduction, dielectric loss, and space charge, during the clean-up and recovery periods.

Several important papers on breakdown in liquids have appeared. Scheu[39] has studied the conditions under which breakdown strength of oils may be regarded as a genuine characteristic of the material under test. At ordinary frequencies he finds necessary the allowance of much longer "rest periods" between breakdowns than those usually stipulated in test specifications. In order to suppress the scattering in breakdown values to the minimum inherent in the nature of the oils, he maintains that the time between breakdowns and also the "rest time" before the first breakdown should be 30 minutes. He recommends that standard specifications be amended to take account of these facts, but it appears doubtful that it will be worth while in routine testing to increase the time required so drastically for the sole purpose of diminishing the scattering of breakdown values. Particularly interesting is the influence of pretreatment voltage impulses reported by this author. He finds that by subjecting the oil to several voltage impulses, the scattering of subsequent breakdown values was much reduced, both with ordinary

Full text of the annual report of the chairman as presented to the 8th annual meeting of the National Research Council's committee on electrical insulation, Pittsfield, Mass., Oct. 17–18, 1935. See also news report, page 1416, this issue.

1. References listed at end of paper.

frequency and with impulse breakdowns, and also that the breakdown strength was increased. He used up to several hundred such impulses before the actual breakdown series. The cumulative effect of a great many such impulses is probably similar to the effect of a direct voltage applied for an extended time, but with impulses lasting only a fraction of a microsecond much higher field strength may be applied without resulting breakdown.

Another interesting and skillful study is that of Strigel[45] on the spread of the observable time intervals of the order 10^{-2} to 10^{-7} second between the application of voltage and the resulting breakdown of small gaps. The time lag of discharge may be divided into 2 parts: the first part is the time during which, for a given impulse voltage and long time dielectric strength of the oil, no breakdown is possible, thus fixing the shortest possible time for the building up of the discharge; the second part, determined statistically, gives the mean spread of the observations of the discharge lag. The minimum building-up time is found to be independent of the electrode materials, but the mean spread of the time lag shows a definite dependence upon the material. An electrode with smaller work function causes a smaller value of the mean spread of the discharge lag. The minimum building-up time is the time necessary for breakdown when all initial conditions are favorable; for example, that at the instant of application of voltage a primary electron is present or just enters the gap from the electrode, and the path of this electron and its resulting avalanche take place in such direction and under such conditions as are most favorable for breakdown, being thus definitely a probability phenomenon. Breakdowns resulting from stresses of less than 10^{-3} second duration are pure ionization phenomena, mechanical and thermal breakdown processes being excluded by reason of the longer time intervals necessary.

Equally important is an extensive review of experiment and various theories of liquid breakdown by F. Koppelman.[21] Of particular interest is his examination of the influence of pressure upon breakdown. He reviews the thermal theory of Günther-Schulze,[16] the gas ionization theories of Nikuradse[30] and of Edler and Zeier,[10] and the electromechanical theory of Gemant[13] in their relations to gas laws and the constants of the liquids, and concludes that no one of them is completely sufficient to explain the facts. He offers, as more satisfactory, a modification of Gemant's idea of a progressively elongated gas bubble. Koppelman assumes that breakdown starts with a minute gas bubble formed on the electrode as a result of any one of several causes, such as a minute discharge from an equally minute surface inequality. The bubble forms, and Koppelman's new proposal is that, in so forming, the surface of the bubble takes the charge from the electrode surface, the bubble itself thereby becoming the electrode. In this way, the bubble elongates and spreads into the liquid, finally forming an electron dart at the leading region of high stress. This picture eliminates the pressure in its effect on gaseous ionization, its influence being limited to its mechanical action as related to the forces of liquid adhesion of electrode, to surface tension, and to other factors bearing upon the actual motion of the head of the bubble.

In my report of last year are comments concerning the opposing theories of breakdown of Edler and Zeier who favor the thermoelectric processes, and of Koppelman who prefers the pure electric or ionization breakdown for pure liquids. Koppelman has presented new evidence in support of his views in a series of studies with a-c flat topped and peaked waves. The results show definite correlation with crest rather than with effective values, thus supporting the theory of pure electric breakdown. These latter results of Koppelman were reported at a conference on insulation research at the Technische Hochschule of Hanover, Prof. H. Schering, director. The published report of this conference contains brief descriptions of other interesting researches, and particularly of recent improvements in methods and equipment for measurements at high voltage.

Further studies of breakdown in commercial oils not completely purified, particularly as related to the influence of pressure, are reported by F. M. Clark.[4] He finds an interesting correlation with the corresponding behavior in gases and suggests a mechanism for breakdown in liquid similar to that in gases.

The chemistry of petroleum insulating oils is reviewed by Dupui[9] with a helpful classification of various types as correlated with chemical stability. From several papers on oxidation, may be mentioned an interesting attempt by Ornstein, Janssen,[31] and Krygsman, to evaluate transformer oils in terms of reaction constants and activation energies. These quantities are found to vary with aging of the oil. With an oil aged for different lengths of time, it was found that the logarithm of the reaction constant plotted against the reciprocal of absolute temperature gives straight lines intersecting at a point. Above this point the reaction constant increases with aging, below it decreases. Hence the conclusion that a certain oil should be used in a transformer only if the point of intersection occurs at a temperature which is above that of operation. Applying this principle experimentally, the authors conclude that a moderately refined oil is better than either a poorly refined oil or a highly refined oil, a conclusion in agreement with practical experience. Making certain assumptions as to the hydrocarbon groups in the oils, the authors offer a quantitative explanation of their results.

The work of Muller[29] agrees with the foregoing as to the existence of a certain optimum in the refining of transformer oils, but in addition this author determines the nature of the oxidation products. Water is found to be an important product in the case of the colorless, highly refined oils, but the primary reaction products are probably peroxides, as established by other workers.

Gases

In the field of breakdown of gases an interesting experimental study of the spark lag of the sphere gap has been reported by Tilles,[48] with a new experimental set-up for the measurement of short time intervals

of the order 10^{-5} second. He concludes that the spark lag may fall into one of 3 distinct domains depending upon the conditions obtaining, notably the external ionizing forces. The sparkover mechanism may take different forms as related to these conditions.

There is a noteworthy revival of interest in corona formation, particularly as associated with continuous voltage. De Fassi[6] studies the laws of d-c critical voltage, current, and loss. He develops empirical formulas and adds a discussion of existing theories, as based on ionic mobilities and space charges. Misere[26] studies the a-c critical voltage and loss over a wide range of frequency, with particular reference to the early formulas of Peek and Whitehead. General agreement is found with suggestion of slight modifications of the constants for the upper ranges of frequency. At the Hanover conference, previously referred to, corona measurements with the Schering bridge were reported indicating a marked departure from the Peek formula for power loss. A new formula, as based on the experiments, is proposed.

Solids

In the field of solids, Böning[2] has extended his theory, that conduction in dielectrics arises from the motion of ions of one sign, to account for anomalous conduction, absorption, and nonuniform potential gradient in solids. Certain experiments in confirmation are reported. He proposes that the increase in loss under alternating stress and also final breakdown are caused by the formation of minute canals caused by the oscillating motion of the ions.

Of particular interest is the work of Tausz and Rumm[47] on the dielectric constant of materials containing water, such as starch, certain powders, and fibrous materials. The isodielectric method of suspension in a liquid of known specific inductive capacity is not reliable for materials which absorb water. The dielectric constant of many materials is influenced in characteristic manner by the water content and it is proposed that this method is available for an approximate determination of water content. From results of studies of the rise of dielectric constant with temperature it is proposed that the absorbed water is in 2 forms: (1) with very small dielectric constant, and described as "solidified" water; (2) described as "movable" water which strongly increases the dielectric constant and makes it much more susceptible to temperature variation. Whitehead and Greenfield[52] also have studied the influence of residual water upon the dielectric constant of cellulose paper, from which studies empirical relations are derived and the moisture content approximately computed. Where comparison is possible, their results are in general agreement with those of Tausz and Rumm.

Practice

In the field of practice may be mentioned the development by Meissner[25] of a new series of solid and molded insulating materials having high thermal conductivity. All are made from organic binding insulators, including the oils, with powdered crystalline substances added. The thermal conductivity is increased from 3 to 8 times with little or no reduction of the dielectric strength of the binder. Also may be mentioned the development by Handrek[18] of a group of rigid materials of ceramic type, of which the principal constituent is TiO_2, suitable for radio capacitors and in which the dielectric constant has a range of values up to 90 with phase difference of the order from 3×10^{-4} to 8×10^{-4} in the high frequency range.

Improvements abroad in oil impregnated paper insulation for power condensers are described by Gönningen[15] and Güthman.[17] The latter, particularly, claims a great advantage in this service for thin, highly purified oils, stating that they are available with low phase difference and loss with a smaller variation of the same with temperature and voltage than the heavier oils, and also that they have a higher and more stable dielectric strength.

In the United States particular attention has been directed to the problem of the stability of high voltage impregnated insulation. This has taken the form of a more intimate examination and analysis of the behavior of the insulation of high voltage cables, both initially and after service, as represented particularly by the study of the radial variation of power factor by the method of Wyatt and by extensive service records such as those reported by Roper.[34] While no definite conclusions as to the cause of ultimate instability are as yet evident from these studies, they have led already to improvements in the electrical characteristics of cables, and are paving the way for deeper researches as to the ultimate causes of oil and paper instability.

As conspicuous examples of the outcome of progressive and widely distributed research, may be noted the development of several new types of extra high voltage cable and the increasing confidence, as represented by several important installations, in the steady improvement of the earlier types of cable in this class. A new type of oil filled cable with type HH segmented conductor, impregnated after installation, is described by Borel.[3] Dunsheath[8] reports further experiments with the "gas-cushion" cable. A 50-kilovolt oil-filled cable with submarine section is reported from Copenhagen. Of outstanding interest are the installations in the Baltimore and Washington tunnels of the Pennsylvania Railroad of exceptional lengths of 132 kilovolt cable, cables of the pressure type with oil as the compression medium, and also of improved types of oil filled cable with oil feed through the hollow conductor.

The helpful contributions of W. F. Davidson and T. Larsen of the Brooklyn Edison Company are acknowledged.

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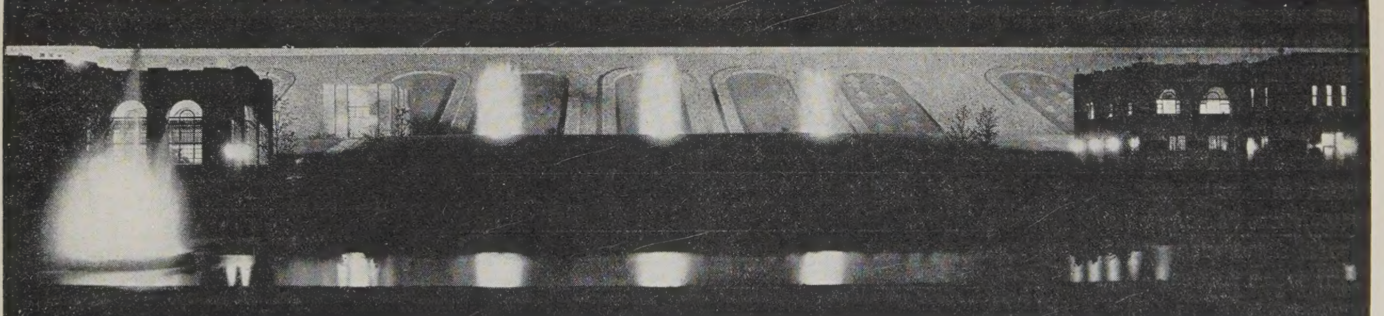

Spectacular floodlighting, as applied to Wanaque Dam of the North Jersey District (N. J.) Water Supply Commission. The dam, 1,600 feet in length and with a slope of 210 feet, is lighted by 50 1,000 watt lamps. At the base of the dam are 3 electric fountains 35 feet high floodlighted by 36 underwater 1,000 watt projectors with colored lenses, and 2 fountains 15 feet high floodlighted by 10 underwater 500 watt lamps. All of the underwater lamps have colored lenses

Magnetic Alloys of Iron, Nickel, and Cobalt

The unexpected magnetic properties of certain alloys of iron and nickel discovered some 20 years ago led to a thorough study of the entire range of iron-nickel alloys. The results of this study were so encouraging that alloys of these metals with cobalt, the only other ferromagnetic metal, also were studied, as well as various alloys of these metals with small amounts of nonmagnetic metals added. From the results of this extended investigation have emerged several alloys that are playing important parts in the continued advancement of electrical communication.

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SOME ALLOYS of iron, nickel, and cobalt have remarkable magnetic properties superior in many situations to those of the constituent metals. Many of these alloys have found wide use in the instrumentalities and circuits of electrical communication, and were developed primarily for that purpose. This paper reports the experience and techniques of the Bell Telephone System in the development and utilization of these materials.

The advantageous properties of these alloys were disclosed through exhaustive researches, during which the whole realm of combinations of these 3 metals was explored. That certain alloys of iron and nickel had unexpected properties at low flux densities had already been discovered in the Bell Telephone Laboratories. There was at that time no theoretical basis for predicting, or even explaining, the character of those alloys; and, therefore, a study was undertaken of the whole iron-nickel series. The results were so encouraging that combinations of these elements with cobalt likewise were studied; and finally those alloys of special interest were combined with varying amounts of nonmagnetic metals. In the course of this investigation several thousand specimens were made and tested in a period extending over 15 years.

A paper recommended for publication by the A.I.E.E. committee on communication, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted Oct. 2, 1935; released for publication Nov. 2, 1935.

Such an empirical investigation is time consuming and expensive, but in a field where so little theory was available for guidance it was the only certain means to determine the practical possibilities of these alloys. It has been justified by the large number of alloys it has developed for practical use in communication engineering. One of the first and most striking applications was to submarine telegraph cables. The largest field of application, however, has been in telephony, where the requirements generally are very exacting, and where other advances have imposed rigid demands on the magnetic materials.

In telephone circuits, standards of transmission efficiency require that the magnetic materials used as circuit elements shall produce maximum magnetic effect with minimum energy loss and distortion of the transmitted currents. Translated into magnetic

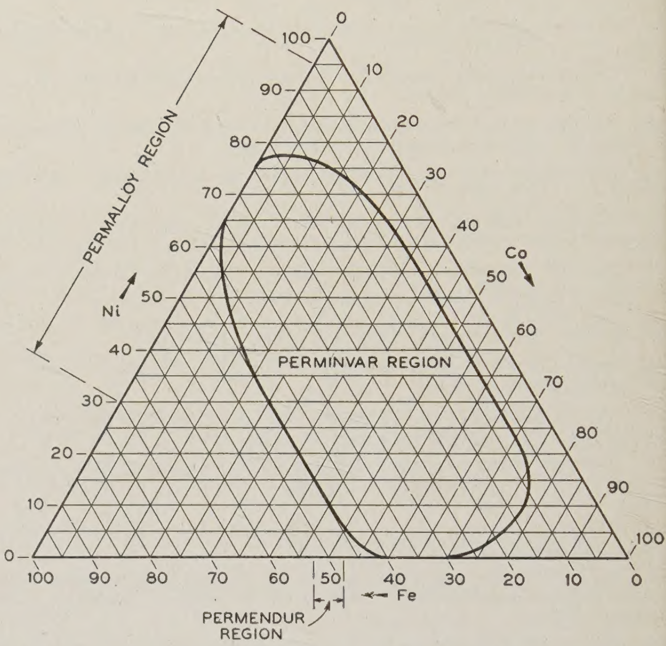


Fig. 1. Composition diagram for alloys of iron (Fe) nickel (Ni) and Cobalt (Co)

characteristics, this means that at low magnetizing forces the material shall have high permeability in combination with low hysteresis loss, and, in many situations, constancy of permeability over the operating range. In circuits for voice and carrier currents it is often necessary to reduce the intrinsic permeability of the material to obtain the required constancy and low losses in the apparatus. Furthermore, to minimize eddy currents, a high resistivity is required and the material must be structurally suitable for fabrication into thin laminations. For other uses, such as for signaling and switching mechanisms, the magnetic properties at medium and high flux densities determine the suitability of the material. High permeability and low coercive force make for improved sensitivity and speed of operation. Low coercive force is of special interest in marginal apparatus where the difference between the operating and releasing currents is small.

Preparation and Composition of the Alloys

A great many factors contribute to the final properties of an alloy. Among the most important of these are the purity of the elements used in the alloy, their preparation, and the heat-treatment. The magnetic properties attainable can be completely masked by the intrusion of small quantities of certain impurities or by improper heat-treatment. For iron the magnetic properties can be improved materially by removing extremely small quantities of carbon and other nonmetallic elements through heat-treating* in an atmosphere of hydrogen and at temperatures close to the melting point. This method of purification also improves the magnetic properties for alloys of iron, nickel, and cobalt. For communication purposes, it has not been found expedient as yet to introduce this method of refinement in the commercial production of these alloys. The purity of the constituents is controlled by ordinary methods of chemical analysis, by methods of melting, and by annealing processes which do not increase the amounts of important impurities. The magnetic properties recorded in this paper, therefore, have been confined mostly to those obtained on materials produced by standard metallurgical methods.

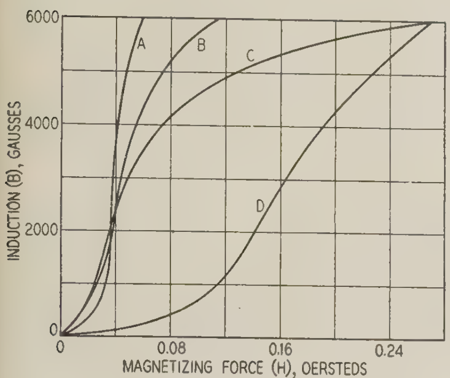


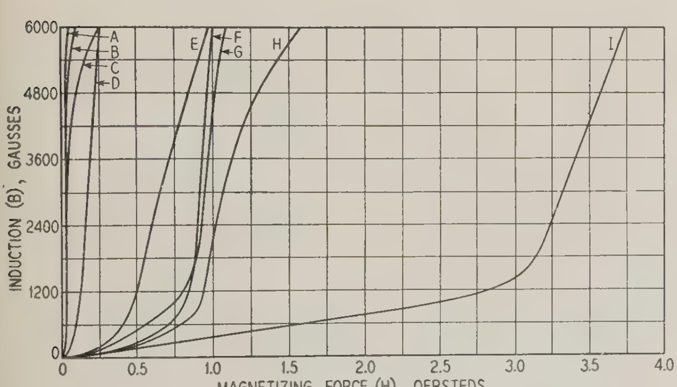
Fig. 2. Magnetization curves for several permalloys for flux densities less than 6,000 gausses

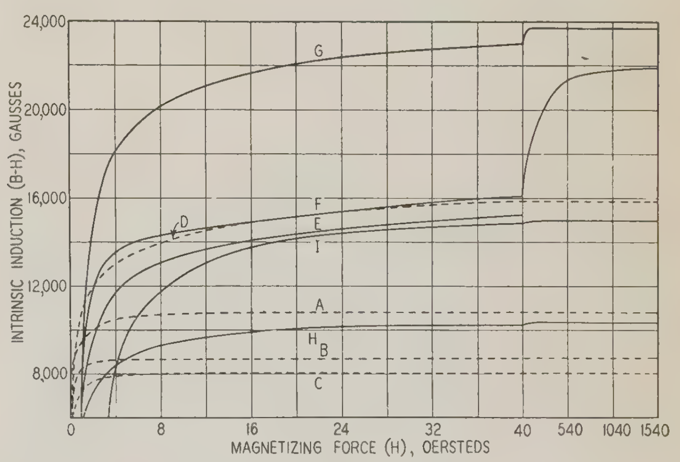
A—78.5 permalloy
B—3.8–78.5 Mo-permalloy
C—3.8–78.5 Cr-permalloy
D—45 permalloy

In the commercial method of producing these alloys the best grades of commercial iron, nickel, and cobalt are used. The melting is done in an electric furnace, and after the mechanical fabrication into suitable shapes these alloys are heat-treated to develop the desired magnetic properties.

Early in an investigation of these alloys it was found that some of them required special heat-treatments to develop the desired magnetic properties. For some the slow cooling incident to the ordinary process of annealing was not suitable, and a rapid cooling was necessary. For another group the slow cooling in the annealing process was not slow enough, and the best results were obtained when the alloys were held at a constant high temperature for a considerable time. It was evident that to determine the most suitable temperature of heating and rate of cooling for each alloy would require more time than was warranted in the exploratory work. Three methods of heat-treatment that, in a general way, would separate the alloys into groups, were developed. These heat-treatments are designated in this paper as "annealing," "quenching," and "baking."

The annealing process consists of heating the samples in closed containers to a temperature of 1,000 degrees centigrade, and cooling with the furnace. The cooling ordinarily requires 7 hours before room temperature is reached. This heat-treatment is primarily for the purpose of removing the effects of mechanical strains necessarily resulting from the rolling and stamping of the alloys into suitable shapes. All the alloys discussed in this paper received this heat-treatment before any of the more special processes were applied.





Figs. 3 (above) and 4 (right). Magnetization curves for permalloys, perminvars, and permendur

A—78.5 permalloy
B—3.8–78.5 Mo-permalloy
C—3.8–78.5 Cr-permalloy
D—45 permalloy
E—Silicon steel
F—"Armco" iron
G—Permendur
H—7–45–25 Mo-perminvar, baked
I—45-perminvar, baked

* There is a rapidly growing technical literature relating to the effects of very small percentages of impurities on magnetic properties and the methods for their removal, with notable contributions by T. D. Yensen of the Westinghouse Electric and Manufacturing Company, W. E. Ruder of the General Electric Company, and P. P. Cioffi of the Bell Telephone Laboratories.

The quenching process consists of heating the alloys for a short time at 600 degrees centigrade, and cooling in air at room temperature for small samples with large surfaces, and in oil for larger samples. The rate of cooling attained by these methods is approximately 40 degrees centigrade per second. It has been

Table I—Designations and Compositions of Some Magnetic Alloys

Designation	Composition, Per Cent					
	Ni	Fe	Co	Cr	Mo	V
78.5 permalloy	78.5	21.5				
80 permalloy	80	20				
45 permalloy	45	55				
3.8–78.5 Cr-permalloy	78.5	17.7		3.8		
3.8–78.5 Mo-permalloy	78.5	17.7			3.8	
2–80 Mo-permalloy	80	18			2	
45–25 perminvar	45	30	25			
7–45–25 Mo-perminvar	45	23	25		7	
Permendur		50	50			
1.7 V-permendur		49.15	49.15			1.7

Ni = nickel; Fe = iron; Co = cobalt; Cr = chromium; Mo = molybdenum; V = vanadium.

found that the best rate of cooling for maximum permeability does not always develop the highest initial permeability. The difference, however, is not large, and often is masked by other variations in the manufacturing process.

The baking process consists of heating the alloys for 24 hours at 425 degrees centigrade, and then slowly cooling to room temperature. The rate of cooling does not affect the development of the magnetic properties unless it is so rapid as to introduce mechanical strains.

Classification of the Alloys

A convenient way of showing graphically the compositions of the alloys of iron, nickel, and cobalt is by means of the composition triangle in figure 1. The sides of this triangle represent the binary alloys of the 3 metals, and points inside the triangle, the ternary alloys.

In this diagram the alloys of special interest because of their magnetic properties are indicated, and, for convenience, each group in which the magnetic properties are similar has been given a specific name.

On the iron-nickel side of the triangle the permalloy region is indicated. In this group several compositions have been developed for commercial use in the Bell System. The method of identifying these alloys consists of prefixing a numeral indicating the per cent of nickel, for example, 45 permalloy contains 45 per cent nickel and 55 per cent iron. To some of these permalloys small amounts of other metals also are added. In designating ternary permalloys the same scheme is extended, so that the name gives everything except the iron content, and this is obtainable by difference. Thus, 3.8–78.5 Cr-permalloy contains 3.8 per cent chromium, 78.5 per cent nickel, and 17.7 per cent iron.

The perminvar region, enclosed by the curved line, contains those compositions that require baking to develop completely their characteristic magnetic properties. The specific compositions of these alloys are indicated by 2 prefixed numerals, the first indicating the nickel and the second the cobalt percentages, respectively. Thus the 45–25 perminvar alloy contains 45 per cent nickel, 25 per cent cobalt, and 30 per cent iron. Another alloy of the perminvar group, in which the nickel and cobalt percentages are the same as the alloy just mentioned, but which contains 7 per cent molybdenum and 23 per cent iron, is designated as 7–45–25 Mo-perminvar.

In the iron-cobalt series of alloys the composition 50 per cent iron and 50 per cent cobalt has been developed for commercial use. This is the permen-

Table II—Magnetic Constants for Alloys Discussed in This Paper

Material	μ_0	μ_m	$W_{H=\infty}$	B_r	H_o	$(B-H)_{H=\infty}$	ρ
"Armco" iron	250	7,000	5,000	13,000	1.0	22,000	11
4% silicon-steel	600	6,000	3,500	12,000	0.5	20,000	50
78.5 permalloy, quenched	10,000	105,000	200	6,000	0.05	10,700	16
45 permalloy	2,700	23,000	1,200	8,000	0.3	16,000	45
3.8–78.5 Cr-permalloy	12,000	62,000	200	4,500	0.05	8,000	65
3.8–78.5 Mo-permalloy	20,000	75,000	200	5,000	0.05	8,500	55
45–25 perminvar, baked	400	2,000	2,500	3,000	1.2	15,500	19
7–45–25 Mo-perminvar, baked	550	3,700	2,600	4,300	0.65	10,300	80
Permendur	700	7,900	6,000	14,000	1.0	24,000	6

Here μ_0 and μ_m are the initial and maximum permeabilities, respectively; $W_{H=\infty}$ is the hysteresis loss in ergs per cubic centimeter per cycle for saturation value of flux density; B_r is the residual induction in gausses; H_c is the coercive force in oersteds; $(B-H)_{H=\infty}$ is the saturation value of the intrinsic induction in gausses; ρ is the resistivity in microhms-centimeter.

dur alloy, indicated in the triangular diagram in figure 1. This alloy is difficult to cold roll, but the addition of 1.7 per cent vanadium improves the mechanical properties and makes it sufficiently ductile to roll into thin sheets. The same system has been followed in designating this alloy as in the case of the permalloys. Thus 1.7 V-permendur is an alloy containing 1.7 per cent vanadium with iron and cobalt in equal proportions.

Table I lists the designations and compositions of those alloys, developed for particular purposes, which are discussed more fully in the remainder of this paper.

In figures 2, 3, and 4 are shown the magnetization curves for low, medium, and high magnetizing forces for these alloys, except the 80 permalloy and the 1.7 V-permendur, for which the curves are substantially the same as for 78.5 permalloy and permendur, respectively. Curves for "Armco" iron and ordinary commercial 4 per cent silicon steel also are shown in these figures. All these materials were annealed, and in the case of the 78.5 permalloy and the perminvars the annealing was followed by quenching and baking, respectively. It may be seen from these curves that the permalloy group reaches almost saturation values long before the iron and silicon steel and the other alloys have reached the lower bend in the magnetization curve. With the exception of the

45 permalloy, which saturates at a fairly high value, the permalloys have low saturation induction and the permendur the highest. The permeability curves computed from these curves are plotted in figures 5 and 6. In figure 5, curves for the permalloy alloys are plotted at a smaller vertical scale than in the figure (6) containing the curves for the other alloys.

The permeability for alternating current of small constant amplitude as a function of superposed d-c magnetizing force is shown in figure 7 for some of the alloys. In most apparatus where both alternating and direct current are involved, this "butterfly curve" must be relatively flat over the expected range of d-c excitation. The important magnetic constants for these alloys are given in table II.

Permalloys

In figure 8 the initial and maximum permeabilities and the coercive force and resistivities are plotted for quenched alloys of the iron-nickel series. These curves show the remarkable variations in magnetic properties with composition in this series of alloys. The permalloy region includes alloys between 30 and 95 per cent nickel, as indicated in figure 1. Some of the alloys in this region, particularly from 50 to 85 per cent nickel, require rapid cooling to develop the magnetic properties indicated in the curves. If they are merely annealed, both the maximum and initial permeabilities are much lower. The greatest effect in reducing the permeabilities by slow cooling appears to be for the alloys containing between 70 and 80 per cent nickel; for example, 78.5 permalloy with a standard anneal has its initial permeability reduced to 1,200. If the alloy is baked for several hundred hours this permeability can be reduced still further to about 500. There is a very rapid decrease in the coercive force as the nickel increases above 27 per cent, and the lowest values are reached in the region between 70 and 80 per cent nickel. The resistivity increases rapidly just below the permalloy region, and reaches maximum at about 31 per cent nickel. It should be noted that the large changes in the coercive force and the resistivity are at the lower end of the permalloy region, while the highest permeabilities are developed in the alloys containing between 75 and 80 per cent nickel.

45 Permalloy. One of the alloys developed for commercial use is 45 permalloy. This attains a saturation flux density as high as any of the permalloys. At 40 oersteds the flux density is 16,000 gausses, substantially the same as for "Armco" iron, and considerably higher than for ordinary silicon steel (figure 4). The initial and maximum permeabilities (under standard practice of heat-treating) are 2,700 and 23,000, respectively (figure 5 and table II). For cores requiring flux densities between 8,000 and 12,000 gausses this alloy is specially useful. The resistivity of the alloy is 45 microhms-centimeter, which is high enough to make it superior for use in cores in a-c circuits. The higher permeability at fairly high values of superposed d-c field, shown in figure 7, also favors its use for some purposes.

78.5 Permalloy. Another alloy long used in the telephone plant is 78.5 permalloy. Quenching develops a higher maximum permeability in this than in any of the other permalloys. Initial and maximum permeabilities of 10,000 and 105,000 readily are developed. The hysteresis loss and the coercive force of quenched 78.5 permalloy are minimum. The saturation flux density of this alloy is between 10,000 and 11,000 gausses, and it is reached with a very low magnetizing force. The rapid rise in the flux density of this alloy for small increments in the magnetizing force and the low saturation flux density are shown in figures 2, 3, and 4.

Initial and maximum permeabilities of 78.5 permalloy are improved by elimination of impurities and also by special care in the quenching process. As

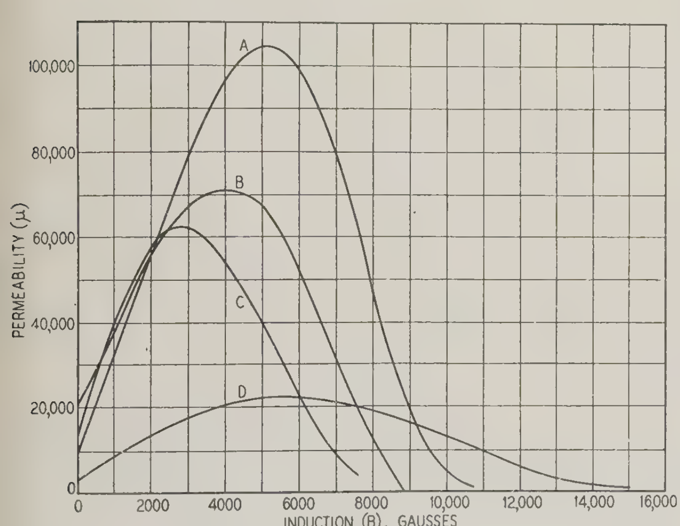


Fig. 5 (above). Permeability curves for permalloys

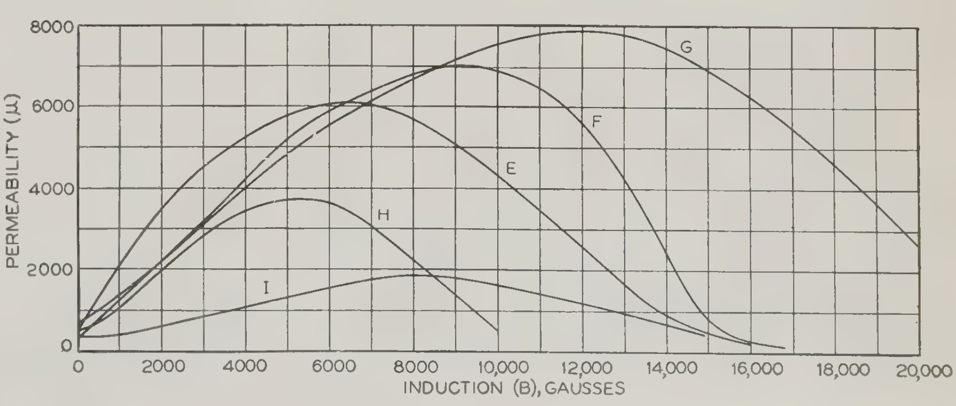


Fig. 6 (right). Permeability curves for perminvars and permendur

A—78.5 permalloy
B—3.8–78.5 Mo-permalloy
C—3.8–78.5 Cr-permalloy
D—45 permalloys
E—Silicon steel
F—"Armco" iron
G—Permendur
H—7–45–25 Mo-perminvar, baked
I—45 perminvar, baked

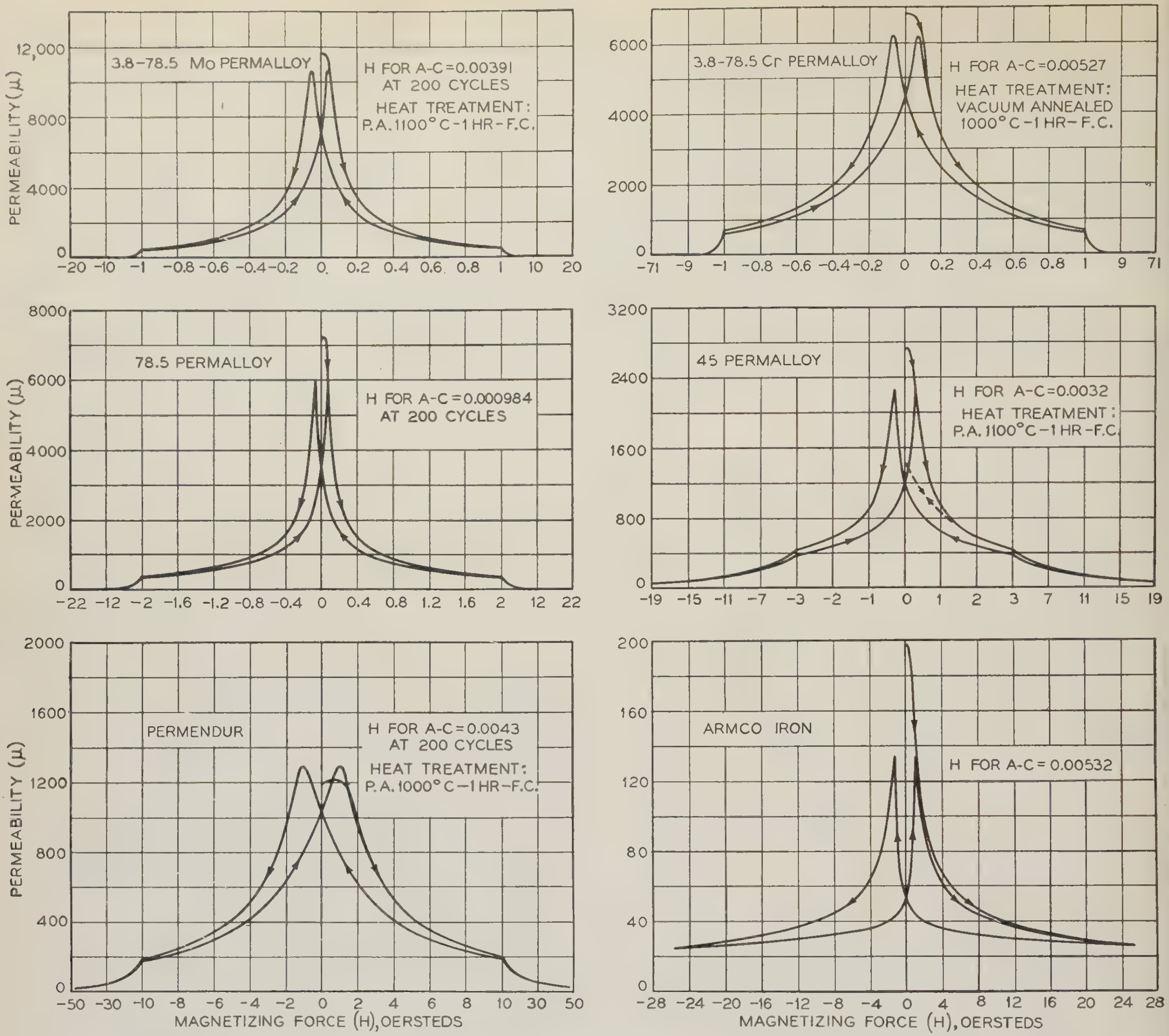


Fig. 7. Effect of superposed d-c fields on the a-c permeability of permalloys and permendurs

P. A.—Pot annealed. F. C.—Furnace cooled (i. e., cooled with furnace)

stated earlier, the rates of cooling required to develop the highest initial permeability differ from those for the highest maximum.

Chromium Permalloy and Molybdenum Permalloy. When other metals are added to permalloys their resistivities, in general, are increased. In research work at the Bell laboratories chromium and molybdenum mostly were used. It was found that with these elements a desirable combination of high resistivity and high initial permeability could be obtained. The variation in resistivity, keeping the nickel content constant at 78.5 per cent, is shown in figure 9. Chromium increases the resistivities somewhat more than molybdenum for a given addition, but the difference is not very large. The 3.8–78.5 Cr-permalloy has a resistivity of 65 microhms-centimeter, as compared with 55 for the 3.8–78.5 Mo-permalloy.

Figure 9 also illustrates the manner in which additions of these metals affect the initial permeability and the sensitivity of the permeability to rate of cooling. The solid line curves are for the annealed and the broken-line curves for the quenched specimens. For the quenched alloys the highest permeabilities are obtained when the added chromium and molybdenum are 2.4 per cent and 1.6 per cent, respectively. For this cooling rate the chromium permalloy seems to develop a slightly higher initial permeability. The difference, however, is small, and a greater spread between different samples has been observed. For the annealed alloys the largest value of initial permeability is obtained with molybdenum permalloy. For 3.8 Mo-permalloy an initial permeability of 20,000 is obtained. With the same heat-treatment the initial permeability of the corresponding chromium alloy is 12,000. It is surprising to note

that small additions of these nonmagnetic metals increase the initial permeability to values considerably higher than that for quenched 78.5 permalloy. Beyond 5 per cent this improvement ceases. All additions decrease the saturation induction values and the maximum permeabilities.

Several of these alloys have been developed for commercial use. Of these the most important are 2–80 Cr-permalloy, 3.8–78.5 Cr-permalloy, and 3.8–78.5 Mo-permalloy.

Perminvar

The distinctive magnetic properties of the perminvars are constancy of permeability at low flux densities, a low hysteresis loss in the same range, and, for medium flux densities, a characteristic constriction in the middle of the hysteresis loop. In some alloys this constriction is so extreme that the coercive force vanishes, making the 2 branches of the loop coincide when the magnetizing force is reduced to zero, in spite of the considerable hysteresis loss involved in the entire cycle. At high flux densities this constriction disappears and the loops have normal shapes.

The degree to which these properties can be developed depends on the composition and the heat-treatment. For the most typical alloys slow cooling in the annealing process produces this effect to a certain degree. Baking for 24 hours in the 400–500 degree (centigrade) temperature range brings most alloys into a stable condition in which no further baking materially will affect the magnetic properties.

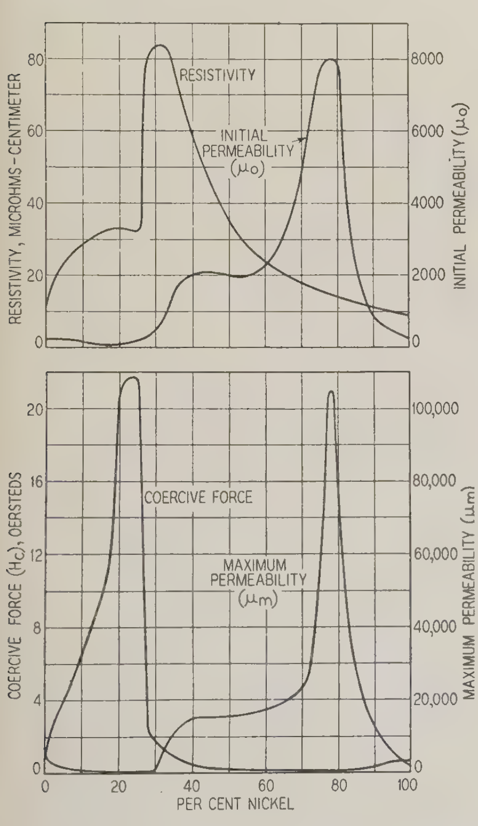


Fig. 8. Resistivity, initial and maximum permeabilities, and coercive force of iron-nickel alloys

As indicated in figure 1, some of the binary alloys tend toward the perminvar characteristics with long baking. Of the permalloys a considerable proportion of those that must be quenched to develop the desirable magnetic properties show perminvar characteristics when they are baked.

45–25 Perminvar. The perminvar characteristics have been developed most intensely in 45–25 perminvar. The magnetization curve in figure 3, and the permeability curve in figure 6, illustrate this fact. The constancy of permeability at low magnetizing forces and the necessity of "baking" to attain this condition are illustrated in one of the sections of figure 10, where the permeabilities are plotted for the quenched and baked conditions. The permeability of the quenched alloy begins to change at very low magnetizing forces, but that of the baked alloy, though lower, remains constant for magnetizing forces up to 3 oersteds.

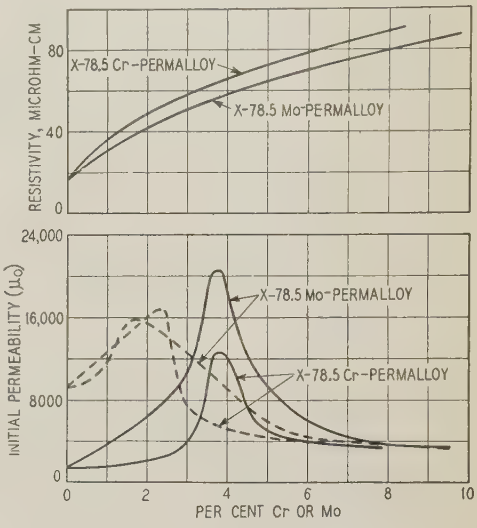


Fig. 9. Resistivity and initial permeability of 78.5 permalloy with chromium or molybdenum replacing part of the iron

In the curve designations, x indicates the percentage of chromium (Cr) or molybdenum (Mo) as read from the abscissa

Hysteresis loops for this alloy in the 2 conditions are shown in figure 10 for maximum flux densities of less than 1,000 and more than 5,000 gausses. For the baked alloy the hysteresis loops for maximum flux densities less than 1,000 gausses cannot be measured by ordinary ballistic methods, because the 2 sides of the loop coincide in a straight line. For loops with higher maximum flux densities the area begins to appear, but the 2 branches of the loop still meet at the origin. Although the coercive force is sensibly zero for the baked alloy until the maximum flux density exceeds 5,000 gausses, the hysteresis loss represented by the loop may become considerably greater than that for the quenched alloy.

7–45–25 Mo-Perminvar. The extremely low hysteresis loss and constancy of permeability at low flux densities makes 45–25 perminvar a suitable material for applications where distortion and energy loss are fatal to good quality of transmission. The resistivity of this alloy is only 18 microhms-centimeter, but it can be increased without serious sacrifice of the low hysteresis characteristic by adding molybdenum. The alloy chosen for commercial use is

7-45-25 Mo-perminvar, having a resistivity of 80 microhms-centimeter.

The manner in which molybdenum affects the magnetic properties is illustrated in figures 3, 4, and 6. The permeability is not quite so independent of the magnetizing force as for the alloy without molybdenum, nor is the hysteresis loss quite so low. The initial permeability for the alloy baked the customary 24 hours is somewhat higher. When baked for a longer period the magnetic characteristics tend more toward those of 45-25 perminvar.

Permendur

An alloy in the iron-cobalt series used in communication apparatus is permendur. The typical composition is 50 per cent iron, 50 per cent cobalt. The outstanding magnetic property of this alloy is high permeability in the range of flux densities between 12,000 and 23,000 gausses (figures 4 and 6). The high permeability of this alloy "endures" to higher flux densities than does the permeability of any other magnetic material. Its initial permeability is about 700, though values as high as 1,300 have been observed for some samples. In addition to the high permeability at high flux densities permendur also has a relatively flat "butterfly" curve, as may be seen in figure 7. For a superposed d-c magnetizing force of 10 oersteds the a-c permeability of "Armco" iron is 40, as compared with 200 for permendur.

1.7 V-Permendur. Permendur is difficult to roll into sheets, because of its brittleness. To overcome this difficulty 1.7 per cent vanadium is added. With this addition it may be rolled into sheets as thin as a few thousandths of an inch. This amount of vanadium affects the magnetic properties only slightly, although larger amounts decrease the permeability at high flux densities.

Another improvement incident to the addition of vanadium is a fourfold increase of resistivity from its value of 6 microhms-centimeter for simple permendur. Permendur, it may be noted, has the lowest resistivity of the iron-cobalt series.

Laboratory Results

As stated hereinbefore, all the alloys that have been discussed have been made on a factory scale for some use in the telephone plant. This paper, however, would be incomplete without mention of some of the remarkable magnetic properties obtained in laboratory samples. In table III some of these magnetic achievements are tabulated. The special treatments given these specimens are noted also in this table.

Engineering Applications

One of the first uses of the permalloys was for continuous loading of a telegraph cable between New York and the Azores laid in 1924. For this project 78.5 permalloy was used in the form of a 0.125 by 0.006 inch tape wrapped helically on a stranded copper conductor. The average initial permeability of this alloy in the laid cable was 2,300, considerably less than can be obtained under the best conditions of heat-treatment and absence of strains. With this loading, the speed of transmitting messages was increased fivefold.[4] By the time a second cable project was undertaken the chromium permalloys had been developed, and 2-80 Cr-permalloy was selected. This alloy has a resistivity of 45 microhms-centimeter, and the initial permeability of the loading on the laid cable was in the neighborhood of 3,700. The increase in permeability and in resistivity increased materially the message carrying capacity.[5]

The largest use of permalloys in the telephone plant has been in cores of loading coils,[6] where the alloy is used in the form of compressed insulated dust. Iron dust cores had been standard for these coils.[7] The lower magnetic losses of permalloy dust, however, permitted utilizing higher core permeabilities. This has resulted in a very material decrease in the size of loading coils. For a high grade loading coil core made from iron dust the effective core permeability at low flux densities had to be limited to 33. The first permalloy used for loading coil cores was 80 permalloy. The insulated and compressed core was designed for an effective permeability of 75—more than double that for the iron dust. Development work on an improved compressed magnetic dust core in which molybdenum is used, is now approaching completion. It is expected that the new material will have a substantially higher permeability than that of the 80-permalloy dust cores,

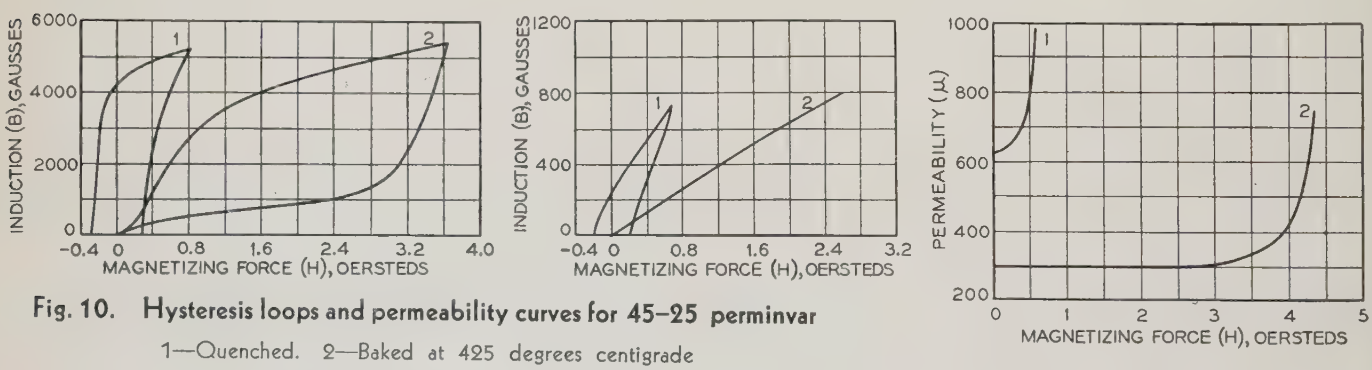


Fig. 10. Hysteresis loops and permeability curves for 45–25 perminvar

1—Quenched. 2—Baked at 425 degrees centigrade

4. For all numbered references see list at end of paper.

and that it will have intrinsically superior eddy current and hysteresis loss characteristics. By virtue of these properties, it will be practicable to make a further substantial reduction in the size of loading coils without sacrifice in service standards. The decrease in the size of the cores with improvement in the core material is illustrated in figure 11.

In d-c apparatus where high permeability and low coercivity are of importance, and where high resistivity does not add to the usefulness of the core material, 78.5 permalloy is suitable. It is used in certain relay structures, usually of marginal type, in which the difference between operating and releasing currents is small.

Table III—Some Remarkable Magnetic Properties Obtained in Laboratory Specimens*

Material	μ_0	μ_m	H for μ_m	H_c	Heat Treatment
"Armco" iron	20,000[1]	340,000[1]	0.021	0.03[1]	18 hr at 1,480 deg C, followed by 18 hr at 880 deg C, both in hydrogen
45 permalloy	11,000	227,000	0.025	0.0145	Melted in vacuum; electrolytic iron and electrolytic nickel; 18 hr at 1,300 deg C in hydrogen
65 permalloy	2,500	610,000[2]	0.0148	0.012[2]	18 hr at 1,400 deg C in hydrogen; heated to 650 deg C 1 hr, cooled in magnetic field of 16 oersteds in hydrogen
78.5 permalloy	13,000[3]	405,000[3]	0.0101	0.0153	$2^3/_8$ x 2 x 0.109 in. tape; annealed; wrapped in 2 layers of 3 mil tape and quenched from 600 deg C in tap water
3.8–78.5 Mo-permalloy	34,000[1]	140,000[1]	0.025[1]		1,400 deg C in hydrogen
Permendur	1,000	37,000	0.22	0.20	940 deg C in hydrogen for 18 hr, slowly cooled to room temperature
Permendur	1,300	29,000	0.27		940 deg C in hydrogen, 6 hr; slowly cooled to room temperature
45–25 perminvar		189,000	0.052	0.059	Heated to 1,000 deg C in hydrogen, reheated to 700 deg C and cooled in hydrogen in a magnetic field of 14 oersteds

For explanation of symbols in headings see footnote to table II.
* Except as noted, the values in this table have not previously been published.

For audio transformers, for retardation coils, and for other apparatus in which high permeability and high specific resistance must be combined, both 3.8–78.5 Cr-permalloy and 3.8–80 Mo-permalloy have been used. The former has slightly higher resistivity, but the latter has higher initial permeability and is more ductile.

While the initial and maximum permeabilities of 45-permalloy are not as high as those of 78.5 permalloy, the higher flux densities attained by the former and its higher resistivity favor its use for certain types of relays and transformers where high flux densities are required. It is used also in some instances for cores of coils that require high a-c permeability when d-c magnetizing forces are superposed.

The magnetic characteristics of the perminvars make them especially suitable for use in circuit elements in which distortion and energy loss must be a minimum; but their relatively high cost, and the advisability of avoiding high magnetization throughout the life of the apparatus, have prevented their

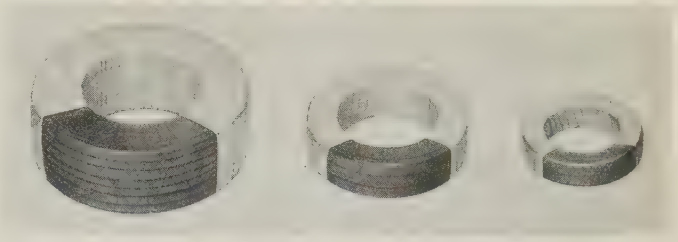


Fig. 11. Equivalent cores for loading coils

Iron dust core (left); permalloy dust core (center); molybdenum permalloy dust core (right)

extensive use in telephone plant. One use for which perminvar is especially suitable is the loading of long submarine telephone cables. Here a high resistivity is very desirable, which has been shown to be obtainable in the 7–45–25 Mo-perminvar. The increase in resistivity resulting from the addition of molybdenum more than offsets the accompanying increase in hysteresis loss, and results in a continuous loading material satisfactory for certain types of loaded cables.

Permendur was developed for use in apparatus where very high flux densities are desired. For a moderate magnetizing force flux densities of 18,000 and 23,000 gausses readily are obtained. It is used for cores and pole pieces in loud speakers, certain telephone receivers, light valves, and similar apparatus.

It may be seen from this survey that there is a great variety of magnetic materials with widely different properties from which an engineer may choose in designing magnetic elements in which magnetic flux changes are essential. Already these alloys have an important place in telephone plant. However, iron and silicon steel still are used extensively, and will continue to hold their own on a cost basis for some purposes. There is no doubt, however, that alloys of iron, nickel, and cobalt will continue to supplant iron and silicon steel in many places where circuits and apparatus are redesigned to take full advantage of their magnetic properties.

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Breakdown Curve for Solid Insulation

A volt-time breakdown curve for solid insulation, constructed from test data obtained with the use of square edged electrodes, is given in this paper, considerably extending the range of information available on this subject.

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INTRODUCTION, within the past few years, of the co-ordination of transformer insulation (with that of the station equipment and adjacent line insulation) has made the question of the dielectric strength of various types of insulation over the complete range of time a very important one.

The 60 cycle characteristics of solid insulation for periods ranging from about one second to several hours is well known. Some information also has been available, for 2 or 3 years, on the impulse volt-time curve of breakdown of pressboard and linen paper insulations for short periods of time. These data showed that the breakdown strength became constant at 3 microseconds and remained constant as far as tested, from 15 to 20 microseconds for the pressboard and from 800 to 1,000 microseconds for thin linen papers. Until just recently very few, if any, reliable data have been available on the breakdown characteristics of the heavier insulations (pressboard) for periods ranging from around 20 microseconds to 1,000,000 microseconds (one second). The importance of this range of the characteristic curves of insulation has been forced upon the attention of the industry by the disclosures of field investigations that lightning waves having a duration of more than from 15 to 20 microseconds quite often are imposed on a substation and the connected apparatus. This apparatus also is often subjected to switching surges where the voltage may last only a few cycles, and the phenomena fall in this range of the characteristic curve.

In figure 1 are shown the results of breakdown tests recently made on single sheets of oil treated $^1/_{16}$ inch pressboard immersed in oil at a temperature of 25 degrees centigrade, where the time ranged from a fraction of a microsecond to 480,000,000 microseconds (8.16 minutes). It may be noted that the curve can be divided into 3 distinct regions.

The first region, marked A, extends from the beginning up to 3 microseconds. In this region the dielectric strength decreases quite rapidly with increase in the time of application of the voltage. This portion of the curve agrees very closely with the average of the data recently published[1,2,11] on barriers composed of solid insulation (pressboard) and oil in series tested between a flat plane and a square edged electrode. A 2.5 x 40 microsecond positive wave was used in making these tests. Overvoltages were applied to obtain the short-time breakdown values which were measured by the cathode ray oscillograph.

The second region, marked B, starts at the 3 microsecond point and extends to around the 50,000 microsecond ($^1/_{20}$ second) point. The dielectric strength is seen to be constant throughout this region.

In the third region, marked C, the strength again decreases, rapidly at first and then more slowly, gradually becoming constant again.

These 3 regions of the curve are somewhat similar to the "Three Regions of Dielectric Breakdown," given in 1930 by Moon and Norcross,[3] except that their case dealt with "strength vs. temperature," whereas this case deals with "strength vs. time of voltage application."

It has not been possible to derive any single equation of "breakdown vs. time" that fits the entire curve of breakdown, and it is very doubtful if one can be derived. It has been shown,[4] however, that from 1 second to several hours' time the volt-time curve can be expressed by a general equation of the form

$$KV = K\left(a + \frac{1-a}{\sqrt[4]{T}}\right) \qquad (1)$$

where

K = the one minute strength
a = constant depending on the material, temperature, etc.
T = time in minutes

The 60 cycle test points so far obtained on this particular material indicate that the value of "a" in equation 1 is 0.35. Time did not permit tests to be obtained for periods long enough to settle definitely whether or not the curve flattens out at 35 per cent of the one minute strength as indicated by the formula. This part of the curve will be determined later.

The $^1/_4$ cycle breakdown points were made by applying a $^1/_2$ cycle wave starting from zero time. Breakdown occurred on the crest. Solid insulation, when subjected to an impulse wave, seldom breaks down beyond the crest of the wave, breaking down either on the front or crest, depending upon the magnitude of the applied voltage.

It may be noted that there is very little change in the breakdown values when going from $^1/_4$ cycle to an alternating voltage of 3, 7, 11, and 18 cycles of 60 cycle frequency.

Aside from the practical value of knowing the shape of the complete volt-time curve of solid insulation, as already mentioned, there is the interest-

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1. For all numbered references, see list at end of paper.

ing question of the mechanism of breakdown throughout the entire range of time. Within the past few years the general theory of breakdown has received, perhaps, more speculation and experimental attack than any similar subject. In 1904 Townsend[5] attributed the breakdown to ionization by collision, and in 1922 K. W. Wagner[6] proposed the pyroelectric theory. This was later modified by Karman,[7] Rogowski,[8] and Drefus.[9] Later, around 1927, Fock[10] gave a complete mathematical solution not only for the resistivity law, $\rho = \rho_0 \epsilon^{-\gamma T}$, but also for the dielectric loss law, $\rho = \rho_1 \epsilon^{-B_1/T}$.

In any of these theories, it is questionable whether very short "time intervals" were experimentally investigated.

It seems quite certain that a mechanism in which "time" plays an important rôle, as it apparently does in region C, does not apply to the entire curve; otherwise the dielectric strength would not remain constant over so long a period of time—from around 3 microseconds to 50,000 or 100,000 microseconds.

As to the cause of the decrease in the dielectric strength for very short intervals of time down to around 3 microseconds, it is suggested that this may be caused by a mechanical effect; that is, by a shattering effect of the voltage on the fibers. Another possible explanation is that the breakdown from near zero to 3 microseconds time is by ionization by collision of the electrons with the molecules during which period "time" is a factor. Beyond this "time" nothing really happens (when voltage is slightly less than the 3 microseconds breakdown value) until heating or corona or both enter as factor.

As to the effect of the sharp edges of the electrodes on the shape of the curve, regions A and C probably were affected to some extent inasmuch as most of the breaks (90 per cent or more) occurred at or near the edges. However, region B apparently was not affected, as the 1/4 to 18 cycle breaks were not confined to any particular part of the surfaces.

The reason for using square edged electrodes instead of electrodes producing a uniform voltage field was that, as already stated, for co-ordination purposes it was desirable to know the shape of the curve under the worst electrode conditions because many insulations in electrical apparatus are not in uniform fields. To test solid insulation as a *material only*, of course, a uniform dielectric field should be used.

It should be understood that this paper is in the nature of a progress report, and that more exhaustive tests may change slightly some of the values, particularly the values at the 2 ends (regions A and C) of the curve. It is believed, however, that no material change will be found in the shape of the flat part of the curve (region B) when using square edged electrodes.

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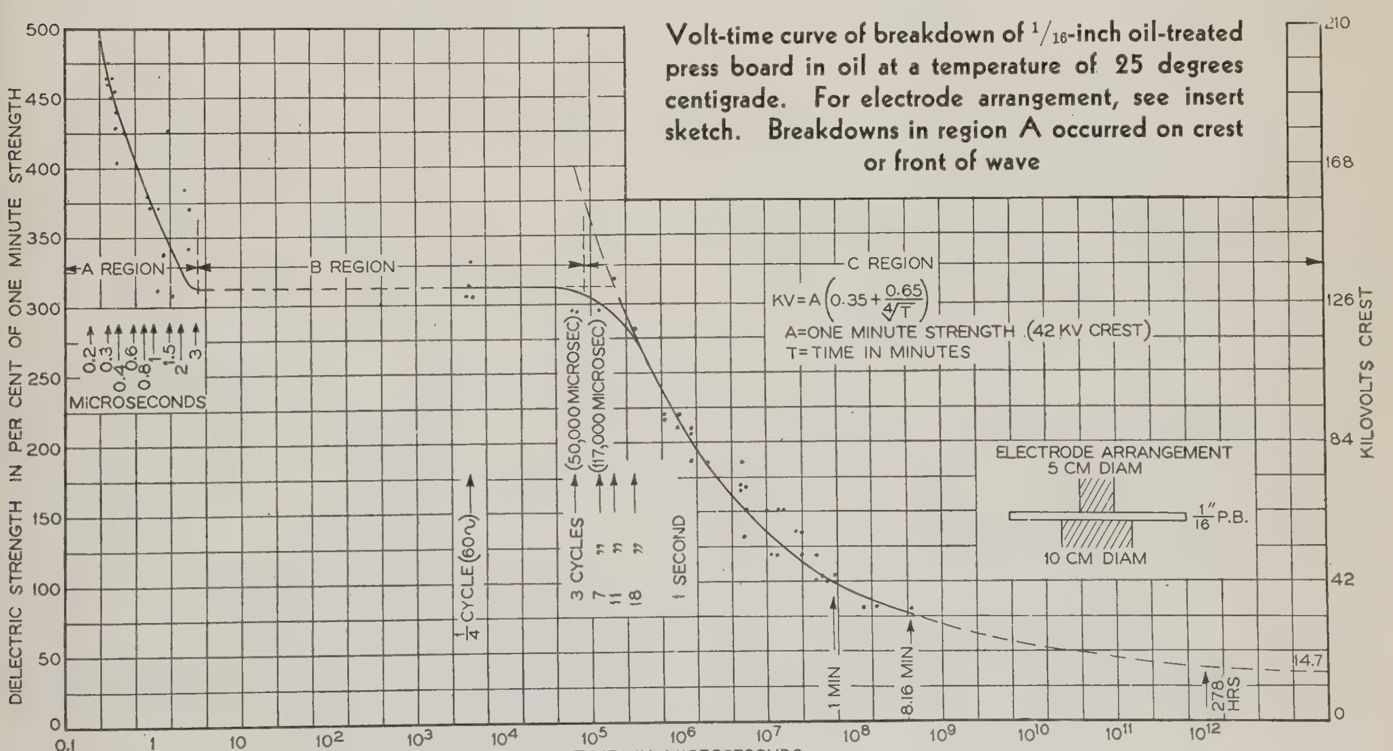

Volt-time curve of breakdown of 1/16-inch oil-treated press board in oil at a temperature of 25 degrees centigrade. For electrode arrangement, see insert sketch. Breakdowns in region A occurred on crest or front of wave

Segregation of Losses in Single Phase Induction Motors

Methods of segregating the load losses in single phase and capacitor induction motors are presented in this paper. Segregation of losses affords a means for checking the accuracy of input-output tests, and is valuable in comparing motors of various designs.

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TO DATE, there are apparently no means published for segregating the load losses of a single phase induction motor. Because of this lack, and for other reasons, the proposed A.I.E.E. Test Code for Polyphase Induction Machines had to be limited to *polyphase* induction machines. This paper makes available methods applicable to the segregation of load losses in single phase and capacitor induction motors. Segregation of losses affords a means for checking the accuracy of input-output tests as well as being of valuable assistance in analyzing and comparing various designs, and can pave the way for extension of the test code. Methods given in this paper have been in practical use for about 5 years on motors ranging from $^1/_{30}$ to 3 horsepower.

Assumptions and Notation

In deriving the equations used in this paper, use is made of the cross field theory as first developed[1] and as further developed in a previously published paper.[2] Use is made also of the revolving field theory,[3] as illustrated by the equivalent circuit of figure 2. The assumptions in this paper are generally similar to those of the 3 papers just mentioned, that is, sinusoidal currents and voltages, sinusoidal space distribution of the stator windings—in other words, harmonic fields are considered negligible—90 degree displacement of stator windings, and a permeability of the iron parts independent of the flux density. In this paper, a further assumption is made that the primary leakage reactance is equal to the secondary leakage reactance; the procedure is clear enough however, so that anyone could go back to the basic equations and derive similar ones by the methods of this paper, except taking into account unequal distribution of reactance.

The notation used in this paper is summarized as follows:

E = impressed volts
r_1 = primary resistance of main winding
r_2 = secondary resistance, referred to main winding
X = "ideal" short-circuit reactance. This is the reactance the motor would have if the secondary winding had zero resistance and were short-circuited

$$= x_1 + \frac{x_2 X_m}{X_m + x_2}$$

X_0 = reactance of primary winding with secondary winding open-circuited

K_r = flux factor $= \dfrac{X_0 - X}{X_0}$

$K_p = \sqrt{K_r}$
$i_m = E/X_m$
I_1 = primary current
I_2 = secondary current in transformer axis (used with cross field theory)
I_3 = secondary current in cross field axis (used with cross field theory)
I_0 = no load current

$S = \dfrac{\text{actual speed}}{\text{synchronous speed}}$

$s = \dfrac{\text{slip speed}}{\text{synchronous speed}}$

R_f = apparent resistance to forward revolving field (see figure 2, also equation 26)
R_b = apparent resistance to backward revolving field (see figure 2, also equation 27)
I_L = measured primary current with rotor locked
W_L = measured primary watts input with rotor locked
$P + r_1$ = real component of impedance with rotor locked, defined in equation 2
Q = reactive component of impedance with rotor locked, defined in equation 3, or "apparent short-circuit reactance"
A = real component of main phase current (capacitor motors)
B = reactive component of main phase current (capacitor motors)
I_m = total main phase current (capacitor motors)
g = real component of capacitor phase current (capacitor motors)
h = reactive component of capacitor phase current (capacitor motors)
I_a = total capacitor phase current (capacitor motors)

K = winding ratio $= \dfrac{\text{effective conductors in auxiliary phase}}{\text{effective conductors in main phase}}$

Determination of Motor Constants

Segregation of losses in single phase motors differs from the segregation of losses in polyphase motors in 3 important respects; (1) The no-load secondary copper loss in a single phase motor cannot be neglected, as shown in figure 4, when determining core loss; (2) the rotor copper loss under load conditions, cannot be computed directly from the slip and output by the simple familiar relation of equation 11; and (3) it is necessary to determine certain fundamental constants of the motor. These fundamental constants are the open-circuit and short-circuit reactances and the actual rotor resistance. These 3 constants, namely, X_0, X, and r_2, can be determined from a reading of watts and amperes at full voltage with rotor locked—primary resistance to be measured immediately at end of "locked" reading—and a

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1. For all numbered references, see list at end of paper.

reading of no load amperes. The primary resistance r_1 can be measured directly by means of a bridge, as eddy current losses in the primary conductors usually can be neglected.

Unfortunately, the interpretation of the no load and "locked" readings is slightly more involved than might be supposed. Using the cross field theory as developed in a previous paper[2] by the author, P. H. Trickey (Diehl Manufacturing Company, Elizabethport, N. J.) gives the following expression for locked-rotor current in some unpublished work:

$$I_L = \frac{E}{(r_1 + P) + jQ} \tag{1}$$

where

$$P = \frac{r_2 K r}{1 + (r_2/X_0)^2} = \frac{r_2(X_0 - X)}{X_0[1 + (r_2/X_0)^2]} \tag{2}$$

$$Q = \frac{X\left(1 + \frac{r_2}{X}\frac{r_2}{X_0}\right)}{1 + (r_2/X_0)^2} \tag{3}$$

Equation 1 was derived directly from equation 9 of the author's previous paper[2] by putting $S = 0$. Trickey later derived the same identical equation by using the circuit of figure 2.

The no-load current from equation 44 of this same paper,[2] is

$$I_0 = \frac{2E}{X_0 + X} \tag{4}$$

Equation 4 is also very readily derivable from the equivalent circuit of figure 2 by putting $s = 0$. Thus, equations 2, 3, and 4 are valid either on the basis of the cross field theory or on the basis of the revolving field theory, as all 3 were derived by each theory separately.

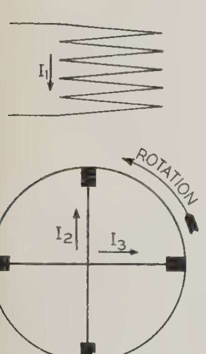

Fig. 1. Representation of the single phase induction motor, based upon the cross field theory

In terms of test results, P and Q are, of course, as follows:

$$P = \frac{W_L}{I_L^2} - r_1 \tag{5}$$

r_1 being measured directly after the locked reading.

$$Q = \sqrt{\left(\frac{E_L}{I_L}\right)^2 - \left(\frac{W_L}{I_L^2}\right)^2} \tag{6}$$

The most accurate method for determining the desired quatities r_2, X, and X_0 from the known values I_0, P, and Q is by simultaneous solution of equations 2, 3, and 4, which yields

$$X = \frac{E}{I_0} - \sqrt{\left(\frac{E}{I_0} - Q\right)^2 + P^2} \tag{7}$$

$$X_0 = \frac{2E}{I_0} - X \tag{8}$$

$$r_2 = \frac{PX_0}{X_0 - Q} \tag{9}$$

It should be noticed that Q, the apparent short-circuit reactance of the motor is always larger than the "ideal" short-circuit reactance, X. This increase in apparent reactance is actually attributable to the rotor resistance. Except for high resistance rotors, such as found in single-value capacitor motors, it is usually accurate enough for segregated loss measurements to take simply $X = Q$ and to proceed using equations 8 and 9. When doubt exists, however, it is safer to use equation 7.

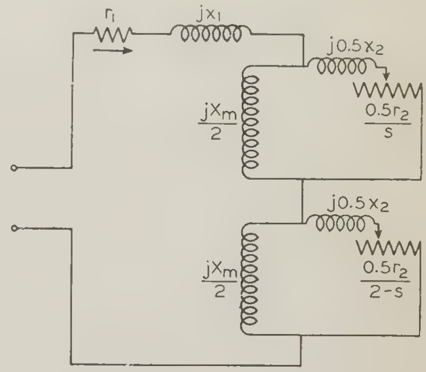

Fig. 2. Equivalent circuit of single phase induction motor, based upon the revolving field theory

The necessary fundamental constants having been determined, one now can proceed to segregate the losses.

Primary and Secondary Copper Losses

The primary copper loss is simply $I_1^2 r_1$, care being taken to correct r_1 to the proper temperature.

In polyphase induction motors, secondary copper loss is a simple function of slip and output:

$$\text{Secondary } I^2R = \frac{s}{1-s}\,(\text{output} + \text{friction}) \tag{11}$$

In single phase motors, no such simple relationship exists, as will be shown in the following analysis. Let b and c be arbitrary constants, defined by the following relations:

$$b = \frac{\text{secondary main field copper loss}}{\text{output} + \text{friction} + \text{cross field core loss}} \tag{12}$$

$$c = \frac{\text{secondary cross field copper loss}}{\text{output} + \text{friction} + \text{cross field core loss}} \tag{13}$$

(The cross field core loss and friction are treated here as part of the mechanical output.)

Referring now to the performance calculation

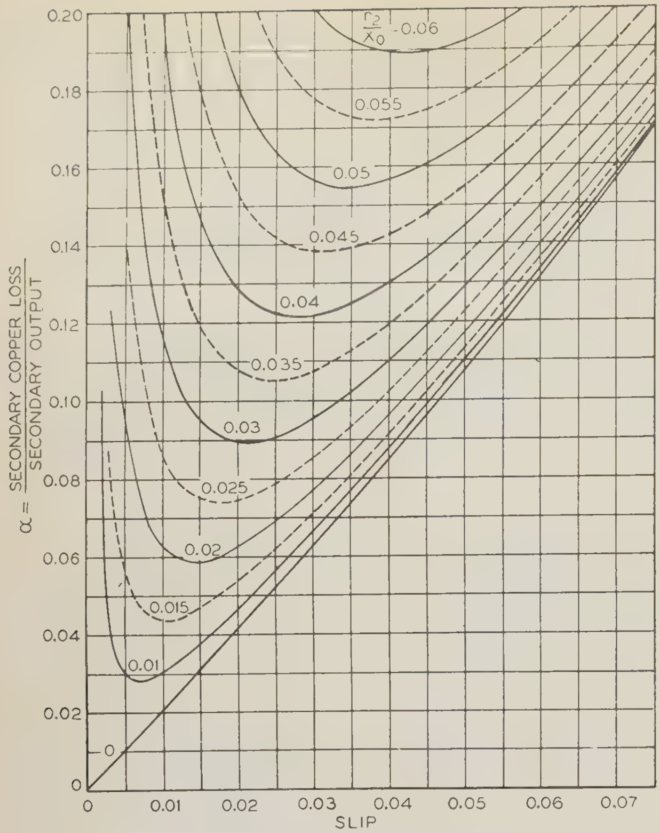

Fig. 3. Secondary copper losses in a single phase induction motor

Slip is expressed as a decimal fraction of synchronous speed

schedule for single phase induction motors, given in a previously published paper,[2]

$$b = \frac{\text{Item 27}}{\text{Item 30}} \tag{14}$$

$$c = \frac{\text{Item 28}}{\text{Item 30}} \tag{15}$$

When r_1, r_2, X, and X_0 are substituted into equations 14 and 15 in accordance with the formulas given in that paper, and the resulting expressions are simplified, r_1 and X drop out and equations 14 and 15 become

$$b = \frac{(1 - S^2)^2 + (r^2/X_0)^2}{[(1 - S^2) - (r^2/X_0)^2]S^2} \tag{16}$$

$$c = \frac{(r_2/X_0)^2}{(1 - S^2) - (r_2/X_0)^2} \tag{17}$$

Now, let

$$\alpha = b + c = \frac{\text{total secondary copper loss}}{\text{output} + \text{friction} + \text{cross field core loss}} \tag{18}$$

Adding equations 6 and 7 and simplifying there is obtained for the total secondary copper loss,

$$\alpha = \frac{1 - S^2}{S^2} + \frac{2\,(r_2/X_0)^2}{[(1 - S^2) - (r_2X_0)^2]\,S^2} \tag{19}$$

or in terms of slip, equation 19 is

$$\alpha = \frac{s(2 - s)}{(1 - s)^2} + \frac{2\,(r_2/X_0)^2}{[s\,(2 - s) - (r_2/X_0)^2]\,[1 - s]^2} \tag{20}$$

Equation 20 is the relation sought between secondary copper loss and output. In figure 3, the ratio α is plotted against slip, s, with the quantity r_2/X_0 as parameter. Thus, in a single phase induction motor, the ratio r_2/X_0 must be known in addition to the slip, to determine the rotor copper loss at any given output.

Core Loss and Friction

Both primary and secondary copper losses must be subtracted from the running-light input to obtain core loss and friction as shown in figure 4. The secondary copper loss when running light is, using the cross field theory,

$$I_2^2 r_2 + I_3^2 r_2 = 2I_2^2 r_2 \tag{21}$$

since $I_2 = I_3$ at synchronous speed. Since I_2 is not directly measurable, it is convenient to express it in terms of the primary current, I_0 as follows:

$$I_0 = \frac{2}{2 - K_p^2}\, i_m \quad \text{(Equation 42 of a previous paper}^2\text{)} \tag{22}$$

$$I_2 = \frac{K_p}{2 - K_p^2}\, i_m \quad \text{(Equation 43 of a previous paper}^3\text{)} \tag{23}$$

Dividing equation 23 by equation 22,

$$I_2 = \frac{I_0 K_p}{2} \tag{24}$$

and

$$\text{No load sec } I^2R = 2I_2^2\, r_2 = \frac{2(I_0 K_p)^2\, r_2}{4} = 0.5\, K_r\, r_2\, I_0^2 \tag{25}$$

which is a simple, convenient equation for practical use. Core loss may be separated from friction by extrapolating the curve of total input minus primary and secondary copper losses to zero volts as shown in figure 4.

Stray Load Losses

In the author's experience, stray load losses in single phase induction motors are of negligible importance. This conclusion was reached after the methods of this paper had been in use for some time to check brake tests, and no noticeable evidence of stray load losses was found. Undoubtedly, however, this point ought to be investigated and reported upon by others.

Three reasons for the apparent absence of stray load loss may be offered:

1. The per cent increase in primary current from no load to full load is much less in a single phase motor than in a polyphase motor; therefore, part of the losses that would appear as stray load losses in a polyphase motor actually would appear in a single phase motor as core loss.

2. Since a tested value of r_2 must be used to compute rotor copper loss in a single phase motor, it is possible that part of the stray load loss appears as rotor copper loss.

3. Since the methods of segregation of losses in single phase induction motors are inherently less accurate than those for polyphase motors, it may be more difficult to detect stray load losses by input-output tests.

Illustrative Example

A $^1/_6$-horsepower, 6-pole 60-cycle 110-volt split-phase motor tested as follows:

	By Brake Test
r_1 cold = 2.48	Full load current = 3.17 amperes
r_1 hot = 1.15 × 2.48 = 2.85	Full load input = 205 watts
r_1 after locked reading 2.54	Full load speed = 1,160 rpm
r_1 after running saturation 2.65	Full load slip = 0.0333
Locked-rotor watts, at 110 volts = 851	Efficiency = 60.6 per cent
Locked-rotor amperes, at 110 volts = 11.65	Power factor = 0.588

Induced voltage at full load = 110 − (3.17 × 2.85 × 0.588) = 104.7 volts

No load current I_0 at 104.7 volts (from figure 4) = 2.58 amperes

From equation 5, $P = \dfrac{851}{11.62^2} - 2.54 = 3.76$

From equation 6, $Q = \sqrt{\left(\dfrac{110}{11.65}\right)^2 - \left(\dfrac{851}{11.65^2}\right)^2} = 7.04$

From equation 7, $X = \dfrac{104.7}{2.58} - \sqrt{\left(\dfrac{104.7}{2.58} - 7.04\right)^2 + 3.76^2} = 6.8$

From equation 8, $X_0 = \dfrac{2 \times 104.7}{2.58} - 6.8 = 74.2$

From equation 9, $r_2 = \dfrac{3.76 \times 74.2}{74.2 - 7.04} = 4.15$

r_2 at 25 deg C $= 4.15 \times \dfrac{2.48}{2.54} = 4.05$

r_2 hot $= 4.05 \times 1.15 = 4.66$

$r_2/X_0 = \dfrac{4.66}{74.2} = 0.0629$

$K_r = \dfrac{74.2 - 6.8}{74.2} = 0.910$

The primary copper loss during the running saturation is 2.65 I_1^2. The rotor copper loss during the running saturation is, from equation 25,

$I_1^2 \times 0.5 \times 0.910 \times 4.05 \times \dfrac{2.65}{2.48} = 1.97\, I_1^2$

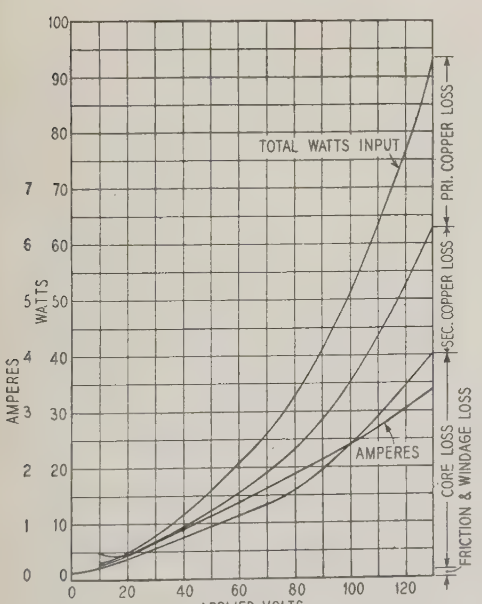

Fig. 4. No-load saturation curve of a typical single-phase induction motor

From the foregoing, the primary and secondary copper losses were computed at each voltage step in the running saturation curve of figure 4 and subtracted from the input as shown. From figure 4,

Core loss + friction loss (at 104.7 volts)	= 26.2
Friction loss	= 1.5
Full load core loss	= 24.7

The full load core loss may be divided arbitrarily into,

Cross field core loss = 12.3
Main field core loss = 12.4

From equation 20

$$\alpha = \frac{0.0333 \times 1.967}{0.967^2} + \frac{2 \times (0.0629)^2}{[0.0333 \times 1.967 - 0.0629^2]\, 0.967^2} = 0.207$$

Now, the losses may be computed:

Cross field core loss	= 12.3 watts
Friction loss	= 1.5 watts
Output	= 124.3 watts
Output + friction loss + cross field core loss	= 138.1 watts
Secondary copper loss = 0.207 × 138.1	= 28.6 watts
Main field core loss	= 12.4 watts
Primary copper loss = 3.17² × 2.85	= 28.6 watts
Total input	= 207.7 watts
Efficiency, by losses = 124.3/207.7	= 60.0 per cent
Efficiency by input-output	= 60.6 per cent

Segregation of losses on this motor is now complete.

Alternative Method of Computing Secondary Copper Loss Under Load by the Revolving Field Theory

Using the equivalent circuit of figure 2, it may be shown that

$$R_f = \frac{\dfrac{0.5\, K_r\, r_2}{s}}{1 + \left(\dfrac{r_2/X_0}{s}\right)^2} \tag{26}$$

$$R_b = \frac{\dfrac{0.5\, K_r\, r_2}{2 - s}}{1 + \left(\dfrac{r_2/X_0}{2 - s}\right)^2} \tag{27}$$

The secondary copper loss is

$$I_1^2\, sR_f + I_1^2\,(2 - s)\, R_b = I_1^2 \left[\frac{0.5K_r\, r_2}{1 + \left(\dfrac{r_2/X_0}{s}\right)^2} + \frac{0.5K_r\, r_2}{1 + \left(\dfrac{r_2/X_0}{2 - s}\right)^2}\right] \tag{28}$$

In the illustrative example,

$$\text{Secondary copper loss} = 3.17^2 \times \left[\frac{0.5 \times 0.91 \times 4.66}{1 + \left(\dfrac{0.0629}{0.0333}\right)^2} + \frac{0.5 \times 0.91 \times 4.66}{1 + \left(\dfrac{0.0629}{1.967}\right)^2}\right] = 26.0 \text{ watts}$$

This value checks quite well with the value, 28.6 found by use of the cross field theory. Equation 28 is probably a trifle easier to use than equation 20.

In thus making use of the revolving field theory, the rotor copper loss is computed from the measured value of primary current instead of from the output as was done when the cross field theory was used. Whether it is inherently and fundamentally more

accurate to use output in preference to primary current, is undoubtedly a debatable question. For polyphase induction motors, the output is used for computing the secondary copper loss.

Segregated Loss Measurements in a Capacitor Motor

Core loss and friction in a capacitor motor may be determined by testing the motor running solely on the main winding. The method is the one described in the preceding paragraphs. The primary copper losses under load can be computed very simply from the measured values of currents in each of the 2 phases and the respective primary resistances of the 2 phases. The loss in the capacitor unit is determined by making a separate measurement of the watts input to the unit at rated frequency and at a voltage which gives capacitor phose current at full load.

There remains, then, only the secondary copper loss to be found. Morrill has shown, in equation 8 of his paper[3] that the equation for the average torque of a capacitor motor, in synchronous watts is

$$T = [I_m^2 + (KI_a)^2][R_f - R_b] + 2K[Ah - Bg][R_f + R_b] \qquad (29)$$

The terms of this equation may be rearranged to show the torque components produced by the forward and backward fields, thus:

$$T = [I_m^2 + (KI_a)^2 + 2K(Ah - Bg)]R_f - [I_m^2 + (KI_a)^2 - 2K(Ah - Bg)]R_b \qquad (30)$$

Now, the secondary copper loss of a polyphase induction motor is equal to the synchronous watts multiplied by the slip. Since the slips of the forward and backward fields are s and $2 - s$, respectively, it is evident that

$$\left.\begin{array}{l}\text{Secondary } I^2R \text{ due to} \\ \text{forward field}\end{array}\right\} = [I_m^2 + (KI_a)^2 + 2K(Ah - Bg)]sR_f \qquad (31)$$

$$\left.\begin{array}{l}\text{Secondary } I^2R \text{ due to} \\ \text{backward field}\end{array}\right\} = [I_m^2 + (KI_a)^2 - 2K(Ah - Bg)](2 - s)R_b \qquad (32)$$

By substituting from equations 26 and 27,

$$\left.\begin{array}{l}\text{Secondary } I^2R \text{ due to} \\ \text{forward field}\end{array}\right\} = [I_m^2 + (KI_a)^2 + 2K(Ah - Bg)] \times \left[\frac{0.5K_r r_2}{1 + \left(\frac{r_2/X_0}{s}\right)^2}\right] \qquad (33)$$

$$\left.\begin{array}{l}\text{Secondary } I^2R \text{ due to} \\ \text{backward field}\end{array}\right\} = [I_m^2 + (KI_a)^2 - 2K(Ah - Bg)] \times \left[\frac{0.5K_r r_2}{1 + \left(\frac{r_2/X_0}{2 - s}\right)^2}\right] \qquad (34)$$

In equations 33 and 34, K is the only unknown. Sometimes it is obtainable from design data. If not it can be obtained by means of a winding ratio test.

Winding Ratio Test. Run the motor at rated voltage, E_m, on the main winding only and measure E_a', the auxiliary winding voltage. Impress E_a, arbitrarily chosen as approximately 18 per cent more than E_a' (the underlying idea is to operate the motor at normal airgap flux), upon the auxiliary winding, and run the motor on the auxiliary winding; then measure E_m', the voltage across the main winding. The winding ratio is,

$$K = \sqrt{\frac{E_a' \times E_a}{E_m \times E_m'}} \qquad (35)$$

Illustrative Example—Capacitor Motor

A 1/4-horsepower 60-cycle 1725-rpm 2-value capacitor motor yielded the following constants:

Hot resistances:

Main winding	$= r_{1m}$	$= 1.68$	$X = 4.79$	
Auxiliary winding	$= r_{1a}$	$= 3.97$	$X_0 = 74.2$	
r_2	$=$	3.75	$K_r = 0.935$	
r_2/X_0	$=$	0.0505	Core loss $= 20.1$	
$0.5K_r r_2$	$=$	1.753	Friction loss $= 11.0$	

Effective resistance of capacitor $= R_c = 2.88$

The primary resistances were measured by a bridge, and r_2, X, X_0, core loss, and friction were determined by the methods of this paper.

	Test Values: Full Load Watts	Test Values: Full Load Amperes, Total	Full Load Amperes Computed From Test: Real	Full Load Amperes Computed From Test: Reactive
Main phase	150	2.31	$A = 1.362$	$B = -1.87$
Auxiliary phase	99	1.09	$g = 0.90$	$h = 0.61$
Line	249	2.55		
Full load slip $= 0.0333$				

K (known from design constants) $= 1.274$

$I_m^2 + (KI_a)^2 = 2.31^2 + (1.09 \times 1.274)^2 = 7.26$

$2K(Ah - Bg) = 2 \times 1.274\,[1.362 \times 0.61 - (-1.87 \times .90)] = 6.40$

$$\text{From equation 26, } sR_f = \frac{1.753}{1 + \left(\frac{0.0505}{0.0333}\right)^2} = 0.531$$

$$\text{From equation 27, } (2 - s)R_b = \frac{1.753}{1 + \left(\frac{0.0505}{1.967}\right)^2} = 1.753$$

The losses may be summarized as follows:

Secondary I^2R due to forward field, by equation 23 $= (7.26 + 6.40) \times 0.531$	=	7.25 watts
Secondary I^2R due to backward field by equation 34 $= (7.26 - 6.40) \times 1.753$	=	1.51 watts
Main winding copper loss $= 2.31^2 \times 1.68$	=	9.0 watts
Auxiliary winding copper loss $= 1.09^2 \times 3.97$	=	4.7 watts
Capacitor unit loss $= 1.09^2 \times 2.88$	=	10.2 watts
Core loss and friction loss	=	31.1 watts
Total losses	=	63.8 watts
Output	=	186.5 watts
Input	=	250.3 watts
Efficiency by losses $= 186.5/250.3$	=	74.5 per cent
Efficiency by brake test $= 186.5/249$	=	74.9 per cent

Segregation of losses on this motor is now complete.

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2. Performance Calculations on Induction Motors, C. G. Veinott. A.I.E.E. Trans., v. 51, Sept. 1932, p. 743–54.

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Measurement of Telephone Noise and Power Wave Shape

Since the original introduction of devices for measuring or rating the wave shape of power system currents and voltages in terms of their influence on exposed telephone circuits, much additional work on this problem has been done; the results of this work are reported in this paper. In part I, a curve of relative interfering effects based upon recent studies is presented, the characteristics of a meter for measuring telephone circuit noise are described, and the results of a comprehensive series of tests on the adequacy of this meter are presented. In part II, a new telephone influence factor weighting curve is presented, and a comparison is given between results obtained by meters embodying weighting networks based upon the new and old curves.

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STUDIES of noise frequency induction problems involving power and telephone systems have shown that power system wave shape and telephone circuit noise commonly contain a number of harmonic frequencies, the important ones lying in the range between about 150 and 3,000 cycles. Due to the characteristics of telephone equipment and the human hearing mechanism there is a wide range in the relative effect of the different frequencies. In the evaluation of inductive co-ordination problems, and the determination of the effectiveness of remedial measures, it is not sufficient to know the magnitudes of the various frequencies present. It is also necessary to have some over-all measurement of the wave shape and noise which bears a definite relation to the effects of noise on a person using a telephone.

A paper recommended for publication by the A.I.E.E. committee on communication, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted Sept. 27, 1935; released for publication Nov. 1, 1935.

1. For all numbered references see list at end of paper.

Of fundamental importance in this problem are the relative interfering effects of various frequencies and the manner in which the individual frequencies combine to produce the over-all result. These factors were discussed in a paper presented before the A.I.E.E. in 1919 by H. S. Osborne,[1] in which the telephone interference factor meter for measuring power system wave shape in terms of its influence on telephone cirucit noise was first proposed. Since that time a large amount of additional work has been carried out on this problem. Part I of this paper discusses a curve of relative interfering effects based upon the results of this work, describes the characteristics of a meter for measuring telephone circuit noise, and gives the results of a comprehensive series of tests on the adequacy of this meter, with particular reference to the accuracy of the curve of relative interfering effects, carried out under the auspices of the Joint Subcommittee on Development and Research of the Edison Electric Institute and the Bell Telephone System. Part II presents a new telephone influence factor weighting curve for rating wave shape based on the data on relative interfering effects of the single frequencies, reviews the factors included in the derivation of the telephone influence factor curve, and compares the results obtained by meters embodying weighting networks based on the new and old curves.

Part I—Measurement of Telephone Circuit Noise

General

The effect of a given amount of noise on a telephone circuit is a complex one, including the masking of speech sounds, distraction of the listener's attention, and annoyance, and may be modified by various factors such as the noise in the room where the telephone is used, talking volume, efficiency of the telephone circuit, and the reactions of the listener, including the manner in which he uses the telephone. It is not practicable in the day-by-day maintenance of telephone circuits to measure all these effects of noise directly. Rather, it is necessary to make some measurement of the circuit noise which may be related to its effect on telephone transmission. It is desirable that the measuring devices used should measure different circuit noises as equal when they produce equal interfering effects on telephone transmission.

Two methods of measuring telephone circuit noise are at present in use in the Bell System. One of these methods is subjective, i. e., uses the human hearing mechanism as a part of the measuring apparatus, and the other is objective or yields noise measurements without the aid of the human hearing mechanism.

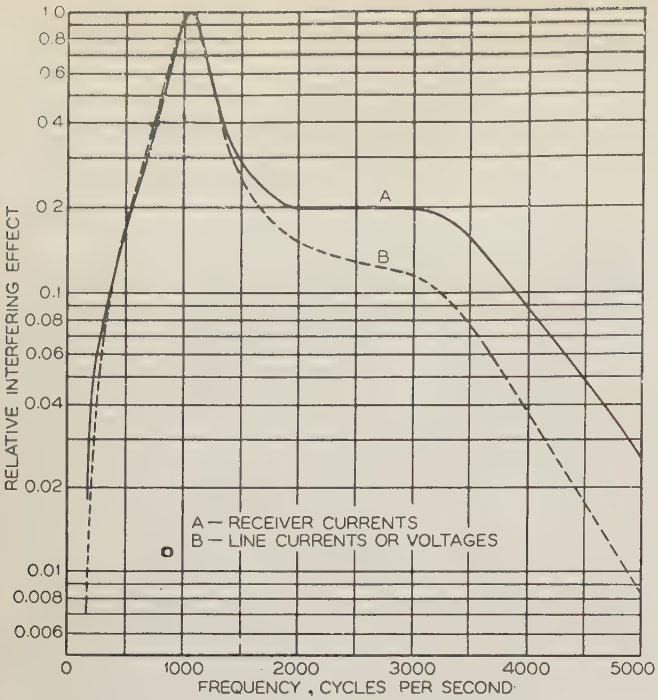


Fig. 1. Relative interfering effects of telephone circuit noise currents

The subjective method is the older of the 2 and has been in use for a number of years. It consists of comparing, in a telephone receiver, the noise to be measured with a noise generated by means of a standard buzzer. The observer may control the magnitude of the buzzer noise by means of a potentiometer until in his judgment it is as disturbing as the noise to be measured. When a balance has thus been made, the result is read directly from the potentiometer.

The objective method of noise measurement has been made available within the last 6 years. It consists chiefly of an electrical network for the weighting of the various single frequency components of a noise in as close accordance as practicable with their interfering effects on telephone transmission, and a calibrated amplifier to raise the energy level of the weighted components sufficiently to operate an electric meter.

One advantage claimed for subjective methods is that they employ the human hearing mechanism, so that it would seem that noises of different types should be measured as equal when they produce equal interfering effects. This apparent advantage is accompanied by the disadvantage, however, that the sensation produced by a given stimulus varies widely for different individuals and for the same individual at different times, so that the average of several measurements by each of several observers is needed for a reasonably accurate result. Also, the theoretical advantage claimed for a subjective method of the comparison type described above is somewhat doubtful, as tests have indicated that even when the average results from several observers are used, the results for noises of different types do not always agree with tests of the interfering effects of these noises made in the presence of transmitted speech.

The chief operating advantages of the objective method are the reproducibility of the results and the ease and speed of making measurements. Its disadvantage lies in the difficulty in determing the complex nature of the hearing mechanism and simulating its characteristics sufficiently well in objective apparatus. Some of the qualities which would be desirable in circuit noise measuring instruments will be discussed as well as the means employed in realizing these qualities.

Indicating Noise Meters

Noise currents of the same magnitude but of different frequencies may produce different effects on telephone transmission. The earliest work of importance in the development of the objective noise meters was directed toward a determination of the relative interfering effects of different single frequency tones. Two types of tests have been used for this purpose, (*a*) judgment tests and (*b*) articulation tests.

In general, judgment tests are set up in such a manner that the observer may compare directly 2 noises in the presence of speech heard over a representative telephone circuit. One of the noises is usually variable in magnitude and is controlled either by the observer or by the person conducting the tests. The 2 magnitudes which the observer judges to be equally disturbing can be measured at a given point in the telephone circuit and, in the case of single frequency tones, the relative weighting which should be applied at that point in the telephone circuit to the 2 tones of different frequency may thus be determined. By using results from a number of observers an average judgment of the relative interfering effects of the 2 noises may be obtained.

An articulation test consists essentially in calling a number of meaningless monosyllables over a circuit to a group of observers, each of whom records the sounds that he hears. The percentage of sounds correctly received is termed the sound articulation for the particular condition tested. Usually each syllable is made up of three sounds (consonant-vowel-consonant) placed in, or at the end of, a sentence, though variations in this technique are sometimes used.[2] On a given circuit 2 different noises which produce the same loss in articulation would usually be considered as equally interfering. As before, in the case of 2 different single frequency noises, measurements at a given point in the circuit could be used to determine the relative weightings to be applied to the 2 noise frequencies.

In 1919 the results of judgment and articulation tests on the relative interfering effects of different single frequency tones were published in the paper by H. S. Osborne.[1] Since that time several other sets of tests have been made, both of the articulation and of the judgment types, in order to check values previously obtained and to bring them up to date.

Noise in the frequency range containing the transmitted speech frequencies most important to understanding, interferes with understanding more than noise in some other frequency range. On the other hand, certain noises produce a harmful effect through annoyance rather than through masking. Thus the

relative interfering effects of different single frequency tones on a telephone circuit are dependent not only upon the characteristics of the human hearing mechanism but also upon the characteristics of the telephone system and may change as the transmission characteristics of the telephone plant change.

From the results of 2 sets of judgment tests and 3 sets of articulation tests, made between 1914 and the present time, a single curve of relative interfering effects of different single frequency tones[3] has been derived. This is shown in curve *A* of figure 1. In deriving it, account has been taken of the trend toward telephone message channels having a more uniform frequency reponse than those used in the past, so that it is expected that this curve and the apparatus based upon it will be useful for a period of years.*

The types of noise usually encountered on telephone circuits are not single frequency but are relatively complex. Hence, it is necessary not only that the proper weighting be used, but also that the method by which the different single frequency components are summed in the human hearing mechanism be simulated in the noise meter.

Information on how single frequencies combine in the human ear is at present incomplete, but it is evidently a very complicated function depending on, among other things, the frequency separation of the components, their levels, their frequencies and probably upon their steadiness. Under these circumstances it was thought best to incorporate a definite rule of combination in a noise meter and then make tests to see how near it came to measuring as equal various complex noises of the types ordinarily encountered in practice which, by tests, produced equal interfering effects. The rule of combination adopted was the rule by which each single frequency contributed to the total meter reading in proportion to its weighted power. (This is the equivalent of the familiar root-sum-square rule for summing currents or voltages.)

In addition to requirements for weighting and rule of combination, it was thought desirable to employ an indicating instrument in which the change of reading was about as rapid as the change in appreciation of loudness in human hearing. From published results[4] and confirming tests it was determined that, on the average, the indicating instrument should reach a full deflection for sounds lasting 0.2 second or longer.

Under these general specifications a few models of circuit noise meters were built and 2 series of tests were made to determine their adequacy for measuring circuit noise. These tests were made by the Joint Subcommittee on Development and Research of the Edison Electric Institute and the Bell System. The first was a rather extensive series of articulation tests on open-wire toll circuit noise, and the second was a series of judgment tests on noise of the type arising by induction in telephone circuits exposed to a-c circuits supplying rectifiers.

* The articulation and judgment tests mentioned here also contributed largely to the selection, by the C.C.I.F. (international advisory committee on telephony), of a curve of relative interfering effects of single frequency tones expressed in terms of voltage across the receiver, which it has recommended as a basis for noise measurement on international circuits. The weighting given in curve *A* of figure 1, when expressed in similar terms is in conformity with the weighting recommended by the C.C.I.F.

Articulation Tests on Open-Wire Circuit Noise

In preparation for the articulation tests[5] on open-wire circuit noise, 2 surveys were made: one of open-wire circuit noise at 6 of the important toll centers in the United States (New York, Chicago, Pittsburgh, Cincinnati, St. Louis, Atlanta) in order that the circuit noises tested might be representative of those actually encountered in practice; and the other of room noise in telephone locations, in order that the room noise conditions used in the articulation tests might simulate those at telephone locations.

In the circuit noise survey, frequency analyses were made of the circuit noises found on a representative number of the toll circuits entering each toll center. These analyses were studied and classified and actual circuit noises, representative of each classification, were recorded on phonograph records. It was found possible to represent the noises measured in the survey by means of nine samples of actual circuit noise, phonographically recorded. These noises were used as a means of determining the adequacy of the noise measuring devices, using articulation as the criterion of interfering effect. A frequency analysis of a representative of these noises is shown in figure 2.

In connection with the room noise survey[6] a study was made concerning the distribution of telephone calls, among cities of different population and among business and residence locations in the United States. Room noise was measured in about 205 telephone locations selected in accordance with the results of this study. After studying the results of the survey a room noise was recorded in which the frequency composition and the sources of noise (people talking, doors closing, etc.) were representative of the room noise present in an average telephone location.

The telephone circuit used in the articulation tests was a representative toll connection consisting of a toll circuit having about 10 decibels loss connected

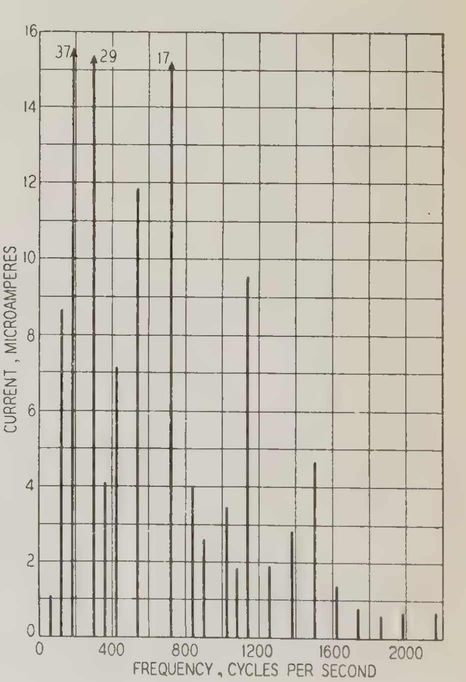


Fig. 2. Frequency analysis of noise current recorded phonographically

at either end to toll switching trunks, local loops, and telephone sets.

The weighting to be applied to single frequency noises depends upon the point in the circuit at which the noise is measured. The weighting shown in curve A, figure 1, is for current in the receiver of the telephone set. Curve B of this same figure shows the weighting at the end of the toll circuit, which is somewhat different from that in the receiver, due to the transmission characteristics between these 2 points. In practice it is more convenient to measure toll circuit noise at the end of the toll circuit than at the subscriber's receiver. Based on curve A of figure 1 and measurements relating current in the receiver to current in the toll circuit, the weighting shown on curve B for use at the end of the toll circuit was derived and built into the model noise meter used in these tests. This noise meter also contained a weighting suitable for use in making measurements of noise voltage across the receiver rather than measurements of noise current in the receiver. This was done only for convenience, the weighting employed being directly related to that shown on curve A of figure 1 by means of the impedance of the receiver at the various frequencies. Because of the small amount of distortion between the end of the toll circuit and the telephone set terminals of the subscriber's loop, weighting B of figure 1 applies about equally well to all points in a telephone circuit between telephone sets.

Both the noise meter and the ear balance measuring device (subjective method described in an early paragraph of part I) were used in measuring the various types of noise tested. It was assumed that when under a given set of conditions, certain magnitudes of the different types of noise produced the same articulation loss, the magnitudes should be measured as equal by a desirable noise measuring device. The extent to which a noise measuring device approached this desirable requirement was determined by examining the difference between measured amounts of the various types of noise which produced a given articulation loss.

The noise meter measured the weighted noise power in each of the various types of noise in terms of decibels above an arbitrarily chosen reference power. The power which has been selected as the reference

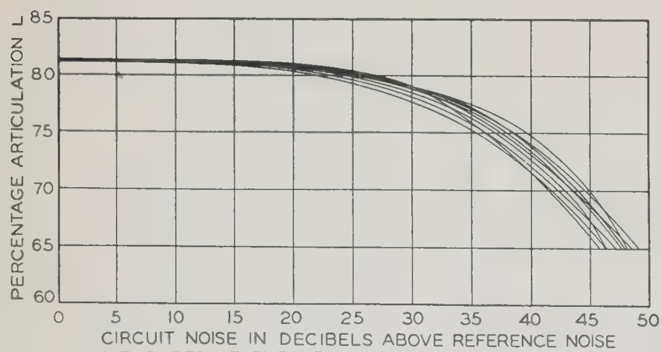


Fig. 3. Articulation versus noise magnitude for 9 different types of circuit noise, as determined with handsets

for circuit noise meter readings is 10^{-12} watts at 1,000 cycles.

In the ear balance measuring device, the potentiometer is calibrated in terms of millionths of the current output of the buzzer flowing through the receiver used in making the balance. Thus the readings of this device are current type units, and have been named "noise units."

Either type of unit may be converted to the other type by means of experimentally determined relations.[5]

The articulation tests showed that when toll circuit noises of various types produced equal losses in articulation under the given set of telephone conditions, they were measured as substantially equal by both objective and subjective methods of measurements. The objective method gave a slightly better correlation than did the subjective even though 18 observers were used in the ear balance tests. The relations between articulation and meter readings of

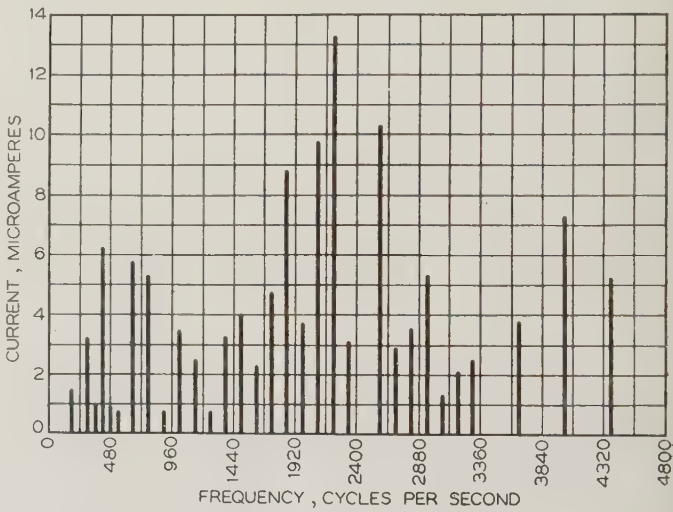


Fig. 4. Analysis of average rectifier noise

noise for 9 types of noise, obtained with handset telephone instruments, are given in figure 3. These relations show fairly good agreement among meter readings of the different noises for a given value of articulation. Similar relations obtained for the desk stand telephone instrument showed about equally good agreements. These agreements among meter readings of different noises were obtained both when the measurements were made at the end of the toll circuit and when they were made at the receiver of the telephone set, using the weightings designed for use at these respective points.

By comparing the relation between meter readings and articulation for the more complex noises with that for those less complex, it was found that the method of allowing each single frequency to contribute to the total meter reading in proportion to its weighted power (root-sum-square rule of addition for currents or voltages resulted in meter readings for complex noises which were somewhat lower than those for less complex noises producing equal articulation loss. This indicated that the rules of com-

bining different component frequencies in the human ear and in the noise meter were somewhat different. It was considered, however, that because of the small differences between the results with complex noises and those less complex, the rule of summing the weighted powers in the various single frequencies would be sufficiently accurate for meter measurements of noise of the type tested.

These results were gratifying since it was apparent that a meter which would rate noises somewhat more consistently than a subjective method employing a group of 18 experienced observers was a distinctly superior noise measuring device. Moreover, the tests were sufficiently extensive to make the results quite reliable. A total of approximately 300 articulation tests were made on the 9 types of noise, in each test about 2,300 syllables being recorded, corresponding to about 7,000 sounds. Thus, in the noise tests with the 2 telephone sets, over 2 million sounds were recorded. In successive tests, the percentage of sounds correctly received could be repeated to within about one per cent.

Judgment Tests on Rectifier Noises

None of the 9 noises used in the articulation tests had components of importance above 2,000 cycles. With the trend toward the greater use of rectifiers on power circuits it appeared desirable to make some further tests of the noise meter on noises arising from such sources, since these noises may contain important components at frequencies above 2,000 cycles. Arrangements were therefore made for judgment tests to be carried out on representative rectifier noise and high-frequency noises derived therefrom. A representative open-wire noise from the 9 noises used in the articulation tests was used as a comparison noise so that the 2 series of tests could be related. Judgment tests, rather than articulation tests, were used both because they were more practicable to make in this case, and because in cases where the chief interfering factor may be annoyance, observers' judgment is probably as good a criterion of interfering effect as articulation.

A representative telephone circuit was used similar to the one used in the articulation tests. In some of the tests 10, in others 20, observers were used. Papers and periodicals were read over the telephone circuit to each observer who was able to switch on alternately the fixed amount of open-wire noise or one of the other noises which he could vary in magnitude. When, in his judgment, one noise was as interfering as the other, measurement of each noise was made both with the model noise meter and with the ear balance noise measuring device.

The noises tested included, in addition to the representative open-wire noise used as a comparison noise, (*a*) a noise with a frequency make-up about the average of the rectifier noises so far analyzed in surveys made under the auspices of the Joint Subcommittee on Development and Research of the Edison Electric Institute and Bell System, and (*b*) 3 bands of noise derived from this, each 500 cycles wide with centers at 2,050, 2,560, and 3,150 cycles, respectively. These bands of noise were intended

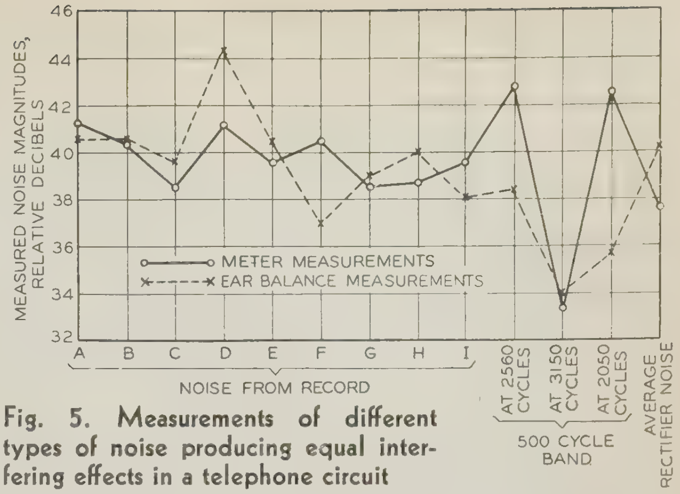


Fig. 5. Measurements of different types of noise producing equal interfering effects in a telephone circuit

to simulate conditions in which resonances in coupled power supply and telephone systems might effectively amplify harmonics falling in certain frequency ranges. A frequency analysis of the average rectifier noise is shown on figure 4.

The tests showed that for amounts of these rectifier noises judged to be equally interfering, neither the meter measurements nor the ear balance measurements were as nearly equal as in the case of the open-wire noises tested by means of articulation. For each of the noises tested appreciable deviations were observed in the magnitudes judged to be equally interfering by different observers. Since this could easily be due to perculiarities in acuity of hearing of the various individuals, the hearing of each observer was tested and no result was used from any observer whose acuity departed greatly from normal in any of the frequency ranges occupied by important components of the noise. The average deviations were of the order of 50 per cent of the average magnitude of noise current. This serves to illustrate the difficulty in judging relative interfering effects when there is a great difference in the types of noises compared. In practice, where the telephone system is used by persons with widely different hearing acuities, the aural effects of bands of noises such as those tested will, of course, vary still more widely.

On the average, the noise meter rated the rectifier noises as well as did the ear balance method with ten observers. Figure 5 shows meter and ear balance measurements of both open-wire noises and rectifier noises producing the same interfering effect as determined by articulation and judgment tests, respectively. The 2 sets of tests have been related by means of the open-wire noise shown in figure 2 which was used as the comparison noise in the judgment tests. Since all the noises produced the same interfering effect, an ideal measuring device would measure them all as equal. Hence, a horizontal line connecting measured magnitudes would indicate an ideal measuring device. The approach to the ideal can therefore be studied by noting how nearly horizontal are the lines connecting the magnitudes given by any measuring device. It may be seen that the values given by the meter are somewhat more constant than are those given by the ear balance method

of measurement. It is also apparent that the correlation is not so good for the rectifier noises as for the open-wire noises.

Meter Method of Measuring Circuit Noise

The advantages of measuring noise by meter methods have been realized for many years and have become increasingly apparent in the light of experience obtained with models of circuit noise meters. Not only are the results more reproducible but much time is saved in making a given number of noise measurements. The tests discussed above indicate that, even with the present incomplete simulation of the human hearing mechanism in an objective meter, the fact that the human ear is not a part of the measuring apparatus is not a disadvantage of importance.

It is, of course, quite possible that for some types of noise not yet tested the meter rating will not be as consistent as for those so far tested. Obviously, not all types of circuit noise have been covered. Further tests are contemplated on other types of noise for the purpose of improving circuit noise meters so that results obtained with them will correlate more and more accurately with effects of noise as determined by the average human ear.

Part II—Measurement of Influence of Power System Wave Shape on Telephone Circuit Noise

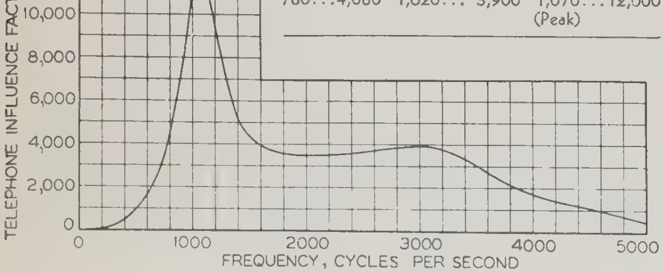
General

A device called the "telephone interference factor meter" for measuring or rating the wave shape of power system currents and voltages in terms of their influence on exposed telephone circuits was described in the Osborne[1] paper of 1919. With this instrument an indication was obtained of the total harmonic content of a given voltage wave, the individual components present being weighted approximately in proportion to their relative interfering effects. The telephone interference factor was expressed in terms of the total microamperes (square root of sum of squares of weighted harmonic components) in the meter branch of a weighting network per volt (effective) applied to the input terminals. Since 1919, this method of measuring wave shape has been used extensively both by the electrical manufacturers and in the field, and telephone interference factor (usually contracted to TIF) has been found a useful quantity both in rating the wave form of electrical machinery and in evaluating the inductive influence of power systems.

Fig. 6. Frequency weighting characteristic for TIF measurements

TIF of Various Single Frequencies

Frequency	TIF	Frequency	TIF	Frequency	TIF
60...	1	900...	7,270	1,740...	3,660
180...	15	1,020...	11,600	1,800...	3,580
300...	205	1,080...	11,980	1,860...	3,570
360...	370	1,140...	11,100	1,980...	3,500
420...	590	1,260...	7,920	2,100...	3,500
540...	1,250	1,380...	5,470	2,500...	3,680
660...	2,250	1,440...	4,740	3,000...	3,940
720...	2,990	1,500...	4,400	5,000...	480
780...	4,080	1,620...	3,900	1,070... (Peak)	12,000



The weighting curve of the original TIF meter was based upon the data on relative interfering effects of single frequencies, obtained during the period from 1914 to 1918, which were limited to the frequency range up to 1,500 cycles. The data obtained from the more recent studies of relative interfering effects described in part I of this paper have made possible a revision[7] of the method of measuring TIF in which the basic principle of the old TIF meter has been retained but in which the frequency weighting characteristic has been revised somewhat and its range extended to approximately 5,000 cycles. In connection with the revision of the weighting curve, the name has been changed to *telephone influence factor* as being a more accurate designation of its function. The new arrangement includes a circuit for measuring the TIF of power system currents as well as that for the measurement of voltages as provided in the original meter. The development of this revision in the method of measuring TIF has been carried on under the direction of the Joint Subcommittee on Development and Research.

Significance of Telephone Influence Factor

The telephone influence factor (TIF) of a voltage or current wave is the ratio of the square root of the sum of the squares of the weighted effective values of all the sine wave components (including in alternating waves both fundamental and harmonics) to the effective value of the wave. The weightings to be applied to the individual components are given in figure 6. The TIF of a power system current or voltage in an inductive exposure is an index to the influence of that particular current or voltage on the noise-frequency induction in the exposed telephone circuits.

As discussed in detail below, the frequency weighting used in determing TIF is derived from the relative interfering effects of single frequencies in a telephone receiver, the frequency characteristic of the transmission path between the toll or trunk circuit terminals and the receiver of the telephone subscriber's set, and the variation with frequency of the inductive coupling between the power and telephone circuits. It will be noted that the above include all the factors relating the voltage and current on the power system to the noise in the receiver of a telephone subscriber's set connected to an exposed telephone circuit, with the exception of the telephone circuit unbalances. In a large majority of cases involving open-wire telephone toll circuits or open-wire telephone subscribers' circuits employing bridged ringers, experience has shown that such telephone circuit unbalances as contribute appreciably to the noise are practically independent of frequency. However, there are certain types of unbalances

which are not independent of frequency, as for example is the case with certain apparatus used in the exchange plant. In these cases, therefore, the TIF may not be a reliable index to the influence of the power system current or voltage. It should also be observed that as a result of the harmonic frequency transmission characteristics of power circuits, the TIF measured at a point on a power system remote from the exposure location may be considerably different from the TIF in the exposure.

It is apparent from the above that the quantitative evaluation of noise in a given situation requires a knowledge of several factors in addition to TIF. Methods of noise calculation have been described in Engineering Reports Nos. 9, 13, 16, and 17 of the Joint Subcommittee on Development and Research. As regards the influence of the power system, it is evident from the manner in which TIF is measured that it expresses the weighted harmonic content of a given voltage or current wave as a fraction of the effective value rather than in absolute units. The total inductive influence of a particular power system voltage or current is, therefore, a function of its effective magnitude as well as its TIF. It is the usual practice to express the influence of a current in terms of the product of its magnitude times its TIF, this quantity being represented by the contraction "$I{\cdot}T$." Similarly, the influence of a voltage is frequently expressed as the product of its magnitude, in kilovolts, and its TIF, this quantity being represented by the contraction "$Kv{\cdot}T$."

Use is commonly made of the residual component of the phase-to-neutral open-circuit voltage TIF of 3 phase machines as an index of their influence when directly connected to a power system and operating with grounded neutral. This quantity, termed "residual component TIF,"[8] is the ratio of the square root of the sum of the squares of the weighted residual harmonic voltages to 3 times the effective phase-to-neutral voltage.

Revised Frequency Weighting Characteristic

The frequency weighting characteristic developed for use in the revised method of measuring TIF is shown in figure 6. TIF weightings taken from the curve for a number of important harmonic frequencies are also given in this figure in tabular form.

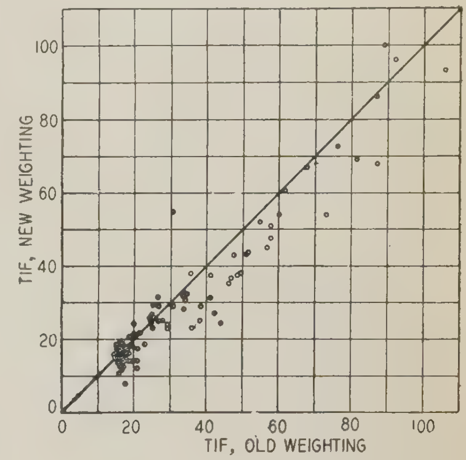
In deriving the revised frequency weighting characteristic, the following factors representing distortion occurring in the various media intervening between the power circuit current or voltage and the telephone subscriber's ear were considered:

1. Relative interference effects of single frequency components in the receiver of a subscriber's telephone set.
2. Distortion occurring between the terminals of the circuit in which the noise is induced and the subscriber's receiver.
3. Variation in coupling between power and telephone circuits with frequency.
4. Variation of effects of telephone circuit unbalances with frequency.

As discussed in part I of this paper, data on items 1 and 2 above were combined to derive the line weighting characteristic of the telephone circuit noise meter indicated by curve B of figure 1. It was, therefore, possible to use this curve directly to represent the combination of these 2 factors.

The work of the Joint Subcommittee has indicated[9] that the noise directly induced in an exposed metallic telephone circuit by a given magnitude of power system harmonic voltage or current is directly proportional to frequency. The noise-longitudinal induced in the circuit composed of all wires of the telephone line in parallel with ground return is similarly proportional to frequency except for that component caused by residual magnetic induction.

Fig. 7. Correlation of new and old TIF's of open-circuit voltage of a-c generators



However, the effect of departure from proportionality with frequency of this particular component within the noise frequency range at a given location is generally not large and is less than the effect introduced by the differences in coupling at different locations resulting from variations in earth conditions. In deriving the revised weighting curve, therefore, coupling between the power and telephone circuit (item 3 above) has been represented by a factor directly proportional to frequency.

Noise-longitudinal acts on such telephone circuit unbalances as may be present to cause noise in the metallic circuit. Experience has shown that in open-wire toll circuits unbalances can, in general, be approximately represented as independent of frequency. This is also true of open-wire subscriber circuits employing bridged ringers. However, unbalances in certain telephone apparatus used in the exchange plant cannot generally be thus represented. Some of these unbalances increase with frequency, some decrease with frequency, and still others increase over one part of the frequency range and decrease over another part. In view of these differing characteristics no type of frequency weighting for unbalances has been incorporated in the TIF curve. Thus, TIF is a correct index for those cases where unbalance is independent of frequency, and in other cases some empirical modification may be necessary.

To summarize the above, the shape of the revised TIF curve was derived from (1) curve B of figure 1 which represents the relative interfering effects of single frequency currents present in the line and (2) a factor proportional to frequency representing in-

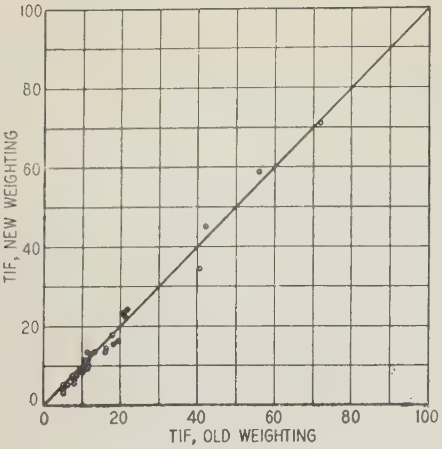


Fig. 8. Correlation of new and old residual component TIF's of open-circuit phase-neutral voltage of a-c generators

ductive coupling between a power line and an exposed telephone circuit.

Correlation Between TIF Measurements With Old and New Weighting Networks

Since a large amount of data has been obtained with the old TIF meter, it was considered desirable, if practicable, to adjust the scale of the revised set so that readings made by this method would in general be approximately the same as readings obtained with the old meter. In this connection calculations using the old and new weightings were made on a large number of machines and circuits of various types on which harmonic analyses were available. These calculations were supplemented by a considerable number of comparative measurements in the factory and in the field using meters employing the old and new weightings. In these measurements particular emphasis was given to the open-circuit voltage wave shape of synchronous machines and to the current and voltage waves on a-c circuits supplying rectifiers. These calculations and tests indicated that, in the average case, reasonably satisfactory correlation between the readings made with the 2 meters would result if a peak value of 12,000 were assigned to the new weighting characteristic as indicated in figure 6. This corresponds with a peak value of 16,400 used with the original TIF meter.

The correlation between TIF magnitudes using the old and new weightings on the open-circuit voltage wave shape of a number of synchronous machines is illustrated in figure 7. The reference line shown is drawn at an angle of 45 degrees. For perfect correlation between measurements by the 2 methods, therefore, the points should fall directly along this line. Comparison of corresponding results obtained (1) for values of the residual component TIF of synchronous machine, (2) from voltage TIF measurements on a-c lines supplying rectifiers, (3) from current TIF measurements on these circuits, are similarly illustrated in figures 8, 9, and 10, respectively.

Calculation of TIF From Harmonic Analyses

Since TIF is the ratio of the square root of the sum of the squares of the weighted components in a current or voltage wave to the effective value of the wave, its value can be calculated if the various component frequencies in the wave are known. The procedure consists in (1) multiplying each component frequency by the corresponding weighting factor shown in figure 6, (2) squaring each of these products, (3) obtaining the sum of these squares, (4) extracting the square root of this sum, and (5) dividing by the effective value of the wave. The quantity obtained in step 4 of this process gives the $I{\cdot}T$ or $Kv{\cdot}T$ product.

The following example illustrates this process as applied to a current wave:

Frequency, Cycles per Second (a)	Frequency Composition, Amperes (b)	Weighting Factor (Fig. 6) (c)	Product of (b)×(c) (d)	Squares of (d) (e)
60	11	1	11	121
180	.6	15	9	81
300	.3	205	62	3,840
540	.02	1,250	25	625
900	.04	7,270	291	84,700
1,500	.02	4,400	88	7,740
1,620	.015	3,900	59	3,480
				100,587

The square root of 100,600 gives 317 as the $I{\cdot}T$ product. Dividing by the effective value of the current gives 28.8 for the TIF.

Devices for Measuring New TIF

Several experimental models of TIF measuring sets meeting the new weighting characteristic have been constructed. The latest of these is designed to operate along the same basic lines as the original TIF meter. It employs a voltage measuring circuit having a somewhat higher input impedance than the original instrument and includes in addition a circuit which may be used, in conjunction with an external shunt, for measuring the TIF of currents. These experimental models have been used on the test floors of the manufacturers and in the field in obtaining the comparative data described above.

The adoption of the rule that coupling will be considered proportional to frequency also makes it possible to use a circuit noise meter and a small amount

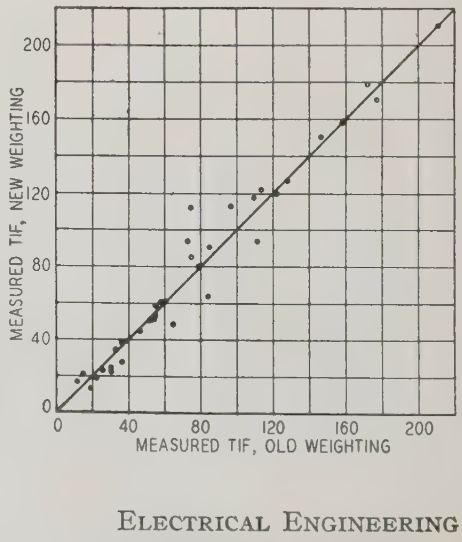


Fig. 9. Correlation of new and old voltage TIF's on a-c circuits supplying rectifiers

of auxiliary apparatus to form a TIF meter. For example, by connecting the input of the noise meter to a power supply circuit through a small capacitance having a much larger impedance than the meter input impedance or the power circuit impedance, a meter reading may be obtained which is equal to 20 log $(A \cdot Kv \cdot T)$ where A is a constant of proportionality. Again by connecting a small inductance

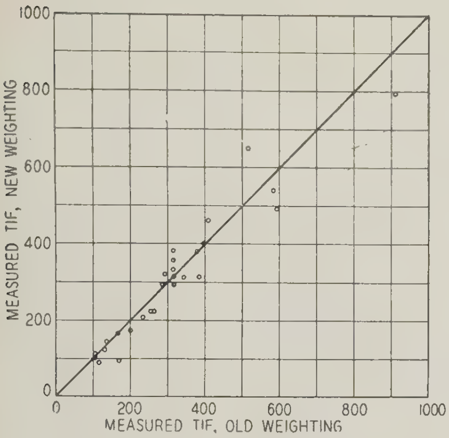


Fig. 10. Correlation of new and old current TIF's on a-c circuits supplying rectifiers

in series with the secondary circuit of a current transformer and connecting the noise meter input across the small inductance, a reading of the noise meter can be obtained which is equal to 20 log $(B \cdot I \cdot T)$ where B is a constant of proportionality. In either case, the proportionality constant may be determined by a single-frequency calibration.

With results from tests made with instruments such as those described above, and a knowledge of the coupling between power supply circuits and telephone circuits, estimates may be made of noise on the telephone circuits. In the past, this method of noise estimation has proved valuable in inductive co-ordination problems. In the future, with revised weighting and improved measuring devices, the method should yield more accurate estimates and should therefore be of greater usefulness.

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* The designation "Engineering Report" refers to reports of the Joint Subcommittee on Development and Research, Edison Electric Institute and Bell Telephone System.

Effect of Total Voltage on Breakdown in Vacuum

The results of a series of high voltage breakdown tests between metal electrodes in high vacuum are reviewed, with consideration of the observed inverse relation between cathode gradient at breakdown and gap length. This leads to the conclusion that the current that flows between electrodes as the conditions for high voltage breakdown are approached must involve positive ions from the anode. The deposition of anode material upon the cathode, which would occur in the event of such positive-ion emission, was found to take place. As final proof of this hypothesis, interelectrode current at constant cathode gradient was found to vary with voltage.

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As a part of a recent investigation[1] of the insulating properties of high vacuum, measurements were made to determine the limiting values of voltage that might be applied between electrodes in vacuum. As the voltage between such electrodes is increased, the attainment of the limiting value is indicated by a very sudden change of the region between electrodes from a condition of insulation to conduction, which occurrence is called breakdown in this paper. The apparatus used for the measurement of breakdown voltage is described in a previous article.[2] It consisted principally of a vacuum tank with a shielded lead-in bushing 38 inches in height, an electrostatic generator, a voltmeter, and auxiliary equipment. A vacuum of the order of 10^{-5} millimeter of mercury could be maintained in the tank, which value was found to be well below that at which results ceased to depend upon pressure. Voltages as high as 500 kv were used. Breakdown data were obtained principally with electrode configurations

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* A doctorate student in the electrical engineering department of the Massachusetts Institute of Technology, Cambridge, during the investigation upon which this paper is based.

1. For all numbered references see list at end of paper.

that would produce between the nearest points of opposite polarity an approximately uniform electrostatic field.

Breakdown Tests

Parameters that were varied during the breakdown measurements were: (1) electrode materials, (2) means of electrode conditioning, and (3) interelectrode distance. A study of the resulting data has led to the phenomenon indicated in the title of this paper, which is considered to be by far the most important outcome of the investigation. The data to be treated in the present article are mainly those which relate to this phase of the results. Consequently, the effects of variation of parameters 1 and 2 are included briefly as a matter of incidental information, while the effect of variation of parameter 3 is considered in detail.

In order to give a comparison of values for different electrode materials, the average voltage required to produce breakdown of a one-millimeter gap after the most effective means of conditioning is given in table I. Various kinds of machinery steels produced surprisingly similar results, and therefore no distinction has been made among them. Though it also gave results practically equivalent to other steels, stainless steel (18 per cent chromium and 8 per cent nickel) is listed separately.

Different methods of electrode preparation and conditioning were tried most thoroughly with steel, which material appeared to give the highest values of breakdown voltage. If it was necessary to smooth the surface of an electrode before it was placed in the vacuum tank, the use of fine emery paper was found to be the best means. The process of polishing and buffing was found to be unessential and often detrimental because of the material that would become imbedded in the electrode. In the vacuum, bombarding the steel electrodes with electrons from a filament usually produced surprisingly little increase of breakdown voltage. Desirable conditioning, however, was obtained with the following treatment. With hydrogen at a pressure of about 1 millimeter of mercury, a discharge was run between electrodes for a period of 3 minutes with a current density of the order of 0.25 ampere per square centimeter. After this the tank again was pumped to a high vacuum, and spark-over between electrodes was produced with the electrostatic generator, the polarity of which occasionally was reversed. This combination of hydrogen discharge and high vacuum sparking usually would result in the attainment of a final breakdown voltage more than double that at which the first spark-over occurred. Sparking with a more powerful source than the electrostatic generator produced about equal breakdown voltages, but was accompanied by serious electrode roughening.

The result of the variation of parameter 3, as stated hereinbefore, leads to the main point of this paper. As the distance between a pair of electrodes (of any of the materials tested) is increased, breakdown voltage is in general not increased at an equal rate. Accordingly, as interelectrode distance and voltage are increased, the average potential gradient

Table I—Breakdown Voltages for One-Millimeter Gap of Various Electrode Materials in High Vacuum

Material	Voltage in Kv
Steel	122
Stainless steel	120
Nickel	96
Monel metal	60
Aluminum	41
Copper	37

at which breakdown occurs is reduced. Since the electrodes of this work were shaped so as to produce an approximately uniform field between their nearest points, this corresponds to the further condition that increases of interelectrode distance and voltage were accompanied by breakdown at reduced electrode gradients. Thus these results indicate that the interelectrode current, which flows as the conditions for high voltage breakdown are approached, must involve more than the mere cathode gradient phenomenon of cold emission that has been considered to be its explanation. An investigation suggested by these results is described hereinafter, following the statement of some essential details of the measurement of breakdown voltage as a function of interelectrode distance.

Configuration and Polarity of Electrodes

Electrodes for the breakdown tests consisted of a one-inch sphere opposite a plane. For most of the work, the plane had a rectangular boundary approximately 3 by 4.5 inches and was placed against a larger plate with rounded edges. For the data carried to 500 kv, the plane was reduced to a 2-inch circle but was surrounded by a group of intermediate-voltage shields.[2]

These dissimilar electrodes would be expected to give a higher value of breakdown voltage with the polarity that corresponds to the lower cathode gradient, i. e., with the plane negative; this was found to be true, especially with the longer gaps. Because of certain deductions (in the discussion that follows) that can be made for the negative polarity, this paper is concerned with the sphere and plane, respectively, as anode and cathode.

Typical Results of Breakdown Voltage Versus Distance

A curve of breakdown voltage versus interelectrode distance is given in figure 1, which represents a run with steel electrodes. Also in this figure the corresponding curve of average breakdown gradient is given; and it should be noted that this quantity varies inversely with distance. Between 0.2 and 4 centimeters, the data for the curve of breakdown voltage very closely fit the empirical relation,

$$v = \frac{590d}{0.77 + d}$$

in which v and d represent, respectively, voltage in kilovolts and interelectrode distance in centimeters.

Though the curves of figure 1 do not represent the best electrode conditioning, they were chosen for inclusion here because of their voltage range. The continuously decreasing slope of the curve of breakdown voltage versus distance, however, is characteristic of all of many breakdown tests covering the variations of materials and conditioning mentioned. That the shape of the curve of figure 1 is thus typical of all the curves of breakdown voltage versus distance is to be emphasized because of its importance in the discussion to follow. Another matter to be pointed out in connection with figure 1 is that these results were usually reproducible to within a few per cent when all conditions of a test carefully were reproduced. This may be judged to some extent by the amount of the deviations from the curve. It does not follow, however, that after taking data for the upper points of such a curve the lower points could be closely checked. The lower portion of the curve would be found to have shifted somewhat as a consequence of the electrode treatment represented by the high voltage spark-over. The resulting curve, however, would still be of the same general character as that given here.

Variation of Maximum Cathode Gradient

The first phase of the investigation suggested by the foregoing variation of average gradient consisted in scrutinizing to some extent the manner in which the maximum gradient upon microscopic surface irregularities of the cathode might vary under conditions of constant average gradient. With the plane cathode and the spherical anode of the breakdown tests, maximum cathode gradient will exist at the base of the perpendicular from the plane to the nearest point of the sphere. With the assumption of a very large plane, an otherwise isolated sphere, and smooth surfaces, maximum cathode gradient may be expressed in terms of the average value on this perpendicular by means of a factor given by Peek.[3] This factor, being a function of interelectrode distance d, will be designated $f_1(d)$. From a value of unity for $d = 0$, it decreases toward the limit zero for $d = \infty$.

Let it be assumed that interelectrode distance d and voltage v are varied proportionately so that a

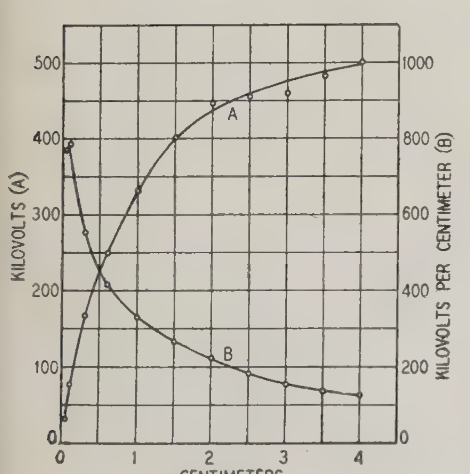

Fig. 1. Breakdown voltage (A) and breakdown gradient (B) versus interelectrode distance

constant average gradient E is maintained along the perpendicular from the plane to the nearest point of the sphere. Obviously, $E = v/d$. On the basis of smooth geometric surfaces, maximum cathode gradient e_s is related to E by the factor $f_1(d)$, or $e_s = Ef_1(d)$. Since $f_1(d)$ is an inverse function of d, maximum smooth-surface cathode gradient varies in an inverse manner with distance.

To determine the manner in which the foregoing reasoning should be modified in order to take into account the effect of a surface irregularity, first reference is made to Bateman.[4] By representation of a surface peak as an ellipsoidal column projecting above a plane, it is shown for a mathematically infinite separation from another plane that there will be a definite ratio of concentration of gradient on the peak of this projection. This ratio of concentration for infinite separation will be designated $f_2(\infty)$. Maximum gradient on the projection will equal, of course, that which would exist on a smooth surface multiplied by $f_2(\infty)$.

Obviously, if the plane with the projection and the opposite smooth plane be moved toward each other, the ratio of concentration will increase continuously, becoming very large as separation becomes comparable with the height of the projection. Thus, the ratio of concentration of gradient is an inverse function of d; it will be designated $f_2(d)$.

In the foregoing case the projection is situated in a region where the electrostatic field would have been uniform in its absence. In the case of a plane and a spherical electrode, an essentially similar condition is obtained if such a hypothetical peak, small compared with the sphere, be mounted on the plane at the base of the shortest line between the plane and sphere. The gradient e_p at the peak of the projection then is related to e_s by $f_2(d)$, or

$$e_p = Ef_1(d)f_2(d)$$

Since both $f_1(d)$ and $f_2(d)$ are inverse functions of d, it follows that the foregoing variation of voltage in direct proportion to interelectrode distance will result in an inverse type of variation of maximum gradient on the assumed cathode peak.

For the actual case of a cluster of different types of irregularities on both the plane cathode and spherical anode, a similar statement regarding the variation of maximum cathode gradient might be vitiated in but one way. As the distance between the plane and spherical electrodes is increased, a larger area of the cathode comes under the influence of a relatively strong field. If the newly exposed region contain a peak sufficiently sharper than any at the center, it might seem possible for an increase of interelectrode distance to be accompanied with an increase of cathode gradient. However, if maximum cathode gradient be related to breakdown voltage, to account for the smooth experimental curves of breakdown voltage versus distance it would be necessary for the cathode to have surface irregularities graded in sharpness as a function of distance from the center of the test spot. Therefore, with the electrodes of the breakdown tests, an increase of electrode separation accompanied by a proportionate increase of voltage could not produce an increase of cathode gradient,

unless there existed during the tests a very special type of distribution of cathode irregularities.

Conclusion From Breakdown Measurements

The experimental curves of breakdown voltage versus electrode separation have been curves of continuously decreasing slope. Therefore, either (1) breakdown occurs at a continuously lower maximum cathode gradient as electrode separation and voltage are increased, or (2) there exists during the tests a distribution of cathode irregularities similar to that contemplated, but accentuated sufficiently to account for the observed decrease of average gradient.

If the condition 1 be valid, the current that leads to breakdown must be attributable to more than the cold emission of electrons, because as gap length and voltage are increased breakdown occurs at continuously lower cathode gradient. This of course might be attributed to gaseous conduction except that the breakdown tests were made at pressures well below that at which results ceased to depend upon pressure. This, however, could be explained on the basis that, as gap length and voltage are increased, the higher voltage electron bombardment causes positive-ion emission from the anode. By bombarding the cathode, such emission could result in electron emission[5] at lower cathode gradients. In this manner, high voltage breakdown at lower cathode gradients could be explained.

Experiments to Check Positive-Ion Hypothesis

As a check upon the foregoing explanation involving the hypothesis that positive ions play a part in high voltage interelectrode conduction at voltages below breakdown, 2 experiments were made:

1. Electrodes of different materials were used to determine whether anode material actually is deposited upon the cathode, which would result if positive ions play the rôle stated hereinbefore.
2. Apparatus was constructed for the measurement of interelectrode current in a region of uniform field and constant electrode area, as voltage and gap length were increased proportionately toward breakdown conditions.

These experiments and their results are described in the following section of the paper.

Electrodes of Different Materials

For an experiment with electrodes of different materials, tests were made with a steel cathode and a copper anode. At the outset, this gap was found to give values of breakdown voltage definitely differing from those for steel electrodes but corresponding to those for copper electrodes. Since interelectrode current must be initiated by cathode emission, the fact that these electrodes displayed the characteristics of the anode material is alone an indication that this material was carried across to the cathode. Since a single instance of this sort might be attributed to the pulling off of loose anode material by electrostatic attraction, the electrodes were moved so that the same anode faced a fresh cathode region. In this way, at a succession of 3 cathode regions, identical results were produced. As a further check, the 3 regions on the steel cathode later were analyzed spectroscopically; strong copper lines were observed, which were entirely missing from other portions of the electrode. Thus it was shown definitely that anode material was transferred to the cathode.

Incidentally, about a 20 minute application of voltage near the breakdown value of these copper-steel gaps was sufficient to produce a visible light brown spot upon the cathode. This of course represents a very small deposition of material, of which quantitative determinations were not attempted.

Electrode for Current Measurement

A description of the apparatus for the measurement of interelectrode current in a region of uniform field and known electrode area follows. The conditions to be secured for this work suggest the use of flat circular electrodes with guard rings; but guard rings, however well fitted, would produce some edge effect. Since cold emission is a function of cathode gradient, any arrangement of cathode guard rings would be open to serious question. For the anode, however, the effects of a guard ring would be much less serious. An anode gradient of 35×10^6 volts per centimeter has been shown to produce no detectable current.[6] In view of these considerations it was decided to use a guard ring on the positive side of the gap.

To meet the second requirement of securing a region of uniform field, a design for that purpose[7] was followed and resulted in the outside contour of the left electrode of figure 2. Other experience of the writer with a pair of electrodes of this type had indicated that within proper limits of gap length they produce a substantially uniform field. (This was indicated by the fact that a large model of this type of gap, which was built for voltage measurement, was found to spark over at random points on the parallel surfaces if the gap length were less than the diameter of the flat area.) As may be seen in the figure, this design was applied in the present investigation only to the anode, and a plane surface was used for the cathode.

The central part of the anode was separated from the outer guard ring by 3 small mica spacers, and 3 mica-insulated clamping screws were used between these parts. The diagram of figure 2 shows one spacer and screw. The conical shield extending to the left from the outer part of the anode was a part

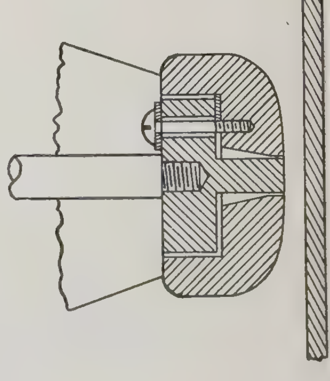

Fig. 2. Guard ring anode and flat cathode

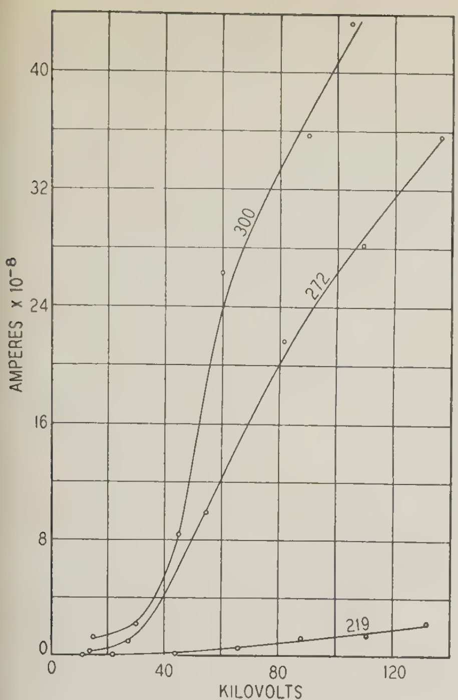

Fig. 3. Current at constant cathode gradient versus voltage

Average gradient (kilovolts divided by interelectrode distance in centimeters) is indicated on curves

of continuous shielding about the connections to the central part of the anode. On the face of this electrode, the radial clearance between the central core and guard ring was 3 mils. In order that the reader may have an idea of dimensions, the diameter of the central core was 0.244 inch, and the relative proportions of figure 2 are fairly accurate. The material chosen was rolled nickel with less than 1 per cent of impurity. Before being used, the guard ring anode and flat cathode were aligned with considerable care. The parts were connected electrically as follows: the cathode directly to the high voltage lead from the generator, the guard ring of the anode directly to ground, and the central portion of the anode through a galvanometer to ground.

Results of Current Measurement

The object of constructing this guard ring anode was to determine whether interelectrode current at voltages below that of breakdown is a function of cathode gradient alone, or whether it may depend also upon voltage. As the most direct experimental approach to this determination, current to the central core was measured while voltage and gap length were increased proportionately so that constant (or slightly decreasing) cathode gradient was maintained. The results of this experiment for 3 values of gradient are shown by curves of current versus voltage in figure 3. These curves show very strikingly that current is a function of voltage as well as gradient.

It might be expected that curves similar to those of figure 3 could be carried over a much greater range of voltage and distance than was done. However, the arrangement of electrodes for current measurement was capable of producing an essentially uniform field in its central region only with gap lengths less than about 0.4 centimeter. With greater separation the region of strongest field would move outward and spark-over likely would occur on the guard ring, especially during runs at the larger gradients. On account of the care taken in shaping and aligning these electrodes, sparking was to be avoided as much as possible. While the data for the curves of figure 3 were being taken, breakdown was avoided until an attempt was made to secure an additional point on the upper curve. After breakdown had occurred, previous data could not be checked; and it thus was indicated that the electrodes had been changed appreciably.

Portion of Total Conduction Attributable to Positive Ions

The positive-ion hypothesis, to explain the manner of variation of breakdown voltage with interelectrode distance in high vacuum, has been checked with 2 types of experiments. The first consisted in detecting the transfer of anode material to the cathode and, like the breakdown voltage analysis, represents a necessary but not a sufficient condition to prove the hypothesis. However, the second type of experiment, which consisted in showing that interelectrode current varies with voltage during the maintenance of constant cathode gradient, does represent a necessary and sufficient condition to prove the hypothesis. Thus it has been shown that positive ions from the anode play a rôle in high voltage conduction between metal electrodes in high vacuum.

In order to determine the fraction of total conduction attributable to positive ions, measurements were made of relative power dissipation on 2 steel electrodes for a few conditions of voltage and spacing. These electrodes consisted of a spherical shell opposite a solid sphere. The former was supported by 3 small wires, and the latter was in contact with another heavy metal part. By this means the temperature of the hollow electrode was made comparatively responsive to energy dissipation, so that its rate of temperature rise might be used as a relative measure of the power received by it. The solid electrode was made unresponsive so that its effects as a source of heat radiation would be minimized. From the voltage readings of a thermocouple, of which 2 of the supporting wires to the hollow electrode were a part, determinations were made of the rate of temperature rise of this electrode operated each way with regard to polarity. As anode the rate was several hundred times the rate as cathode. This indicated that only a small fraction of a per cent of total conduction is directly attributable to positive ions. Consequently, their principal effect is to cause electron emission at lower gradients by bombardment of the cathode.

Although the foregoing hypothesis concerning positive ions is quite unlike that based upon previous investigations, it should be pointed out that the voltage range considered herein far exceeds that of previous work. The upper limit of the breakdown tests, 500 kv, is 17 times the highest value for which similar data could be found in technical literature. In a 17-fold extension it is not surprising that a new effect might be observed.

As a designation for the dependence of interelec-

trode current upon voltage (in addition to cathode gradient), the term "total-voltage effect" has been suggested by R. J. Van de Graaff, who predicted its existence.[8]

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The Engineering Development of Electrochemistry and Electrometallurgy

Some notes on the engineering development of electrochemical and electrometallurgical industries are given in this paper, with particular attention to progress of these industries in France. A discussion of the general problem of supplying electric power to these industries is followed by data on the development of certain processes which significantly illustrate "direct uses" of electricity in industrial processes. This paper by a distinguished French engineer contains considerable information not readily available in the United States.

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THE transformation which the electrochemical and electrometallurgical industries have undergone during the first third of this century takes an entirely different aspect depending upon one's viewpoint. While one observer is impressed by the power of modern apparatus, its perfection, dependability, and the systematic organization of the plants, another observer considers rather the manufacturing processes, the chemical reactions which they bring into play, and according to the latter person, changes have been rather slow during recent years.

A paper recommended for publication by the A.I.E.E. committee on electrochemistry and electrometallurgy, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted Aug. 30, 1935; released for publication Oct. 2, 1935.

Translated from the French by L. A. Huguemont of the General Electric Company, Schenectady, N. Y.

The principal or key chemical methods, which were applied in the most important manufacturing processes, have remained the same, and most substances produced by these industries were manufactured long ago in the same manner as they are now; thus industries covering the production of calcium carbide, ferroalloys, chlorine and chlorates, aluminum, sodium, graphite, abrasives, and many others have remained practically unchanged from the purely chemical viewpoint.

However, the chemist does not ignore the progress made, often by adaptations of older methods, in industries more modest as regards quantity or value of the products. Among these processes may be mentioned the igneous electrolysis which produces alkaline and alkaline-earth metals (the most remarkable one of which is probably glucinium or beryllium), which are extensions of already-known preparations of aluminum and sodium. Cerium as incorporated in igniting devices such as cigar lighters has become a serious competitor of the match.

The same applies to the production of zinc by aqueous electrolysis permitting utilization of poor ores, to the plating by nickel, chromium and other metals, as well as for the preparation of superoxidized substances and to the preparation of cyanides.

The number of products which can be obtained by means of arc furnaces has increased, high temperature fusion has been developed, and fused silica is found in numerous applications.

The purely gaseous arc had given rise to hopes, especially as regards the direct fixation of atmospheric nitrogen, but notwithstanding its great simplicity, this method is now put in the background because of its poor electric efficiency. On the other hand, indirect rival methods, such as the fixation of nitrogen by means of calcium carbide for the production of cyanamide, the compression of a mixture of nitrogen and hydrogen—the latter even resulting from the electrolysis of water—which compression may be followed by the oxidization of the ammonia thus produced, so as to obtain nitrates, all these

methods require only $^1/_3$, or even less, of the electric energy required by the arc alone.

Effects of Fluctuations in Power Supply

Electrochemical and electrometallurgical processes require in most cases electric energy at very low cost. It can be seen easily that with the ordinary rate schedules—no matter how fair they are—which apply to the mechanical and textile industries (generally located in the vicinity of important centers of power production), that the cost of the energy for electrochemical and electrometallurgical processes would sometimes attain the sales price of the products.

For this reason water power plants were resorted to, necessitating higher installation costs than coal burning plants but once installed, operating without great expense. This advantage was formerly even more pronounced because of the moderate interest rate required for the capital investment.

Each hydroelectric plant produced the electric energy which was required for the manufacturing process or processes under consideration. The output of power from these plants is variable, depending upon the hour, day, and season. As a matter of fact, many old Alpine stations have their output reduced in winter to $^1/_4$ or even less of the maximum power obtained during the warm season. Another limiting feature is that the quantity of manufactured products must follow the market fluctuations.

To take care of such variations and fluctuations several manufacturing processes may be combined. Take, for instance, the electrolytic manufacture of aluminum which proceeds at temperatures exceeding 900 degrees centigrade and which demands rather careful supervision and is badly affected by fluctuations. Waterfalls subjected to strong annual variations necessitate the gradual shutting down of the plant and considerable slackening of the operation for several months. Not to mention the larger equipment and the more rapid wear and tear this condition entails, it requires besides a much higher specific consumption (in kilowatt-hours per kilogram of metal produced). Sometimes several weeks are necessary in order that the production of an aluminum cell (or furnace) may attain the production obtained during a very regular program, especially as daily fluctuations must be reckoned with. Among others, rather old observations may be mentioned relating to this point and showing that the specific consumption of the first 122 operating days of a group of 40 furnaces taking a total of 10,500 amperes was 31.4 kilowatt-hours per kilogram, while; when the first 30 days were deducted, the consumption was reduced to 26.7 kilowatt-hours per kilogram and when the first 60 days were deducted, the specific consumption became 24.9 kilowatt-hours per kilogram, a value which was then retained for the remainder of the operation, and became even somewhat lower. It has been estimated that an aluminum plant supplied from a hydroelectric installation under the condition of variations in power supply frequently encountered would have a specific

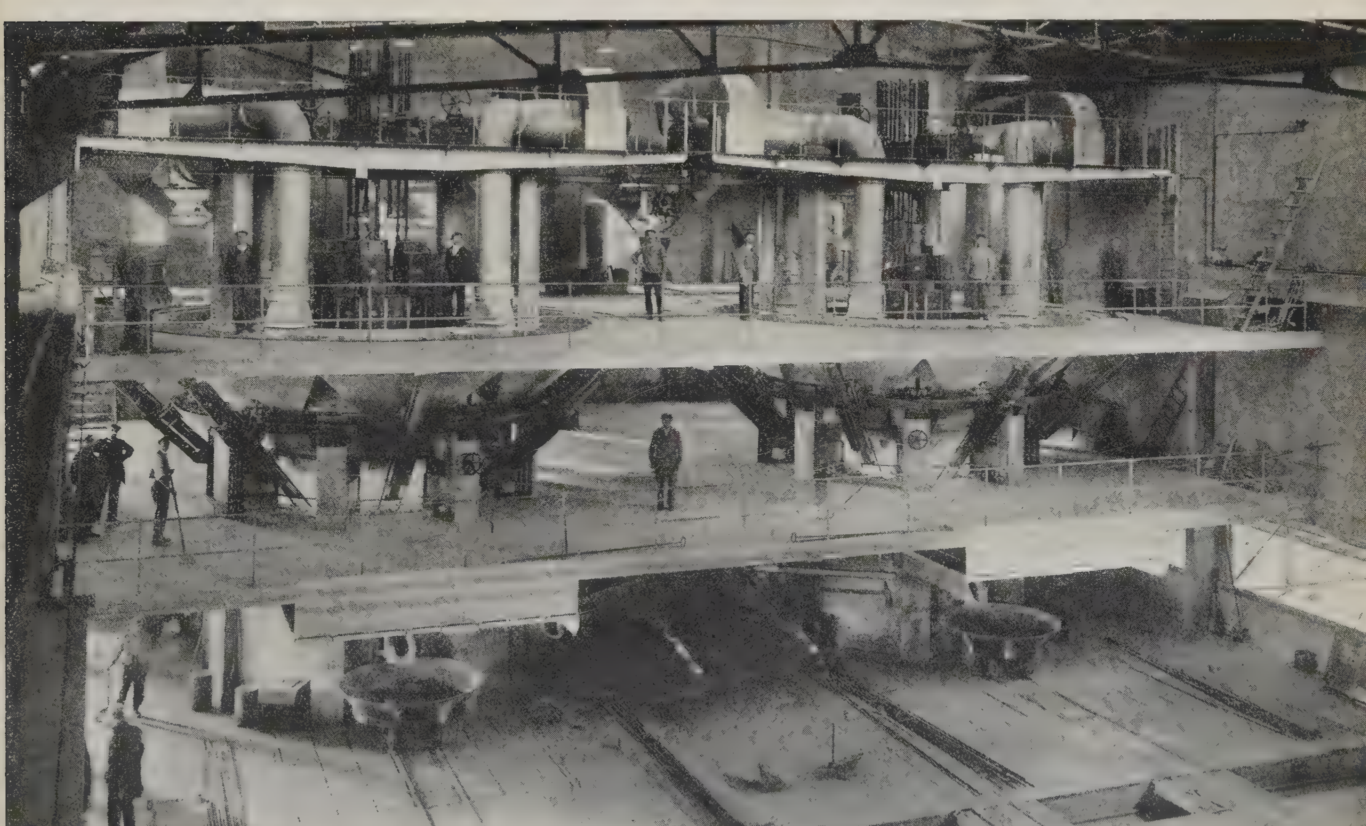


Fig. 1. General view of 2 16,000 kva single phase Miguet-Perron furnaces operated on a 2 phase circuit. See page 1326 for a description of this furnace

over-all energy consumption $^1/_8$th greater than that required, with a constant power supply.

In contrast to this, the manufacture of calcium carbide can withstand much better certain transient variations, the more so the larger the furnace. Moreover, the furnaces do not require that long starting period during which the output is mediocre; after a little time they reach normal operating conditions, and for this reason one can consider starting and stopping the furnaces for periods attaining sometimes 2 weeks at the most.

Aqueous electrolyses allow variations that are even more pronounced. One of the oldest industries, the electrolysis of sea salt solutions, that produce chlorine when diaphragms are used and chlorates when no diaphragms are used, bears readily limited variations in the case of chlorine, with some inconveniences however, but wide variations in the case of chlorates. For instance, a sodium chlorate cell with a normal rating of 2,500 to 3,000 amperes can be operated over the range of 3,500 to 100 amperes without affecting particularly the specific consumption. Another example of this kind is the electrolysis of water. Such processes can be used to absorb secondary power under widely varying conditions. However, such combinations of different industries are bound to be limited, not only because of the necessity of employing conjointly many engineering experts and much technical equipment, but also because of purely commercial considerations.

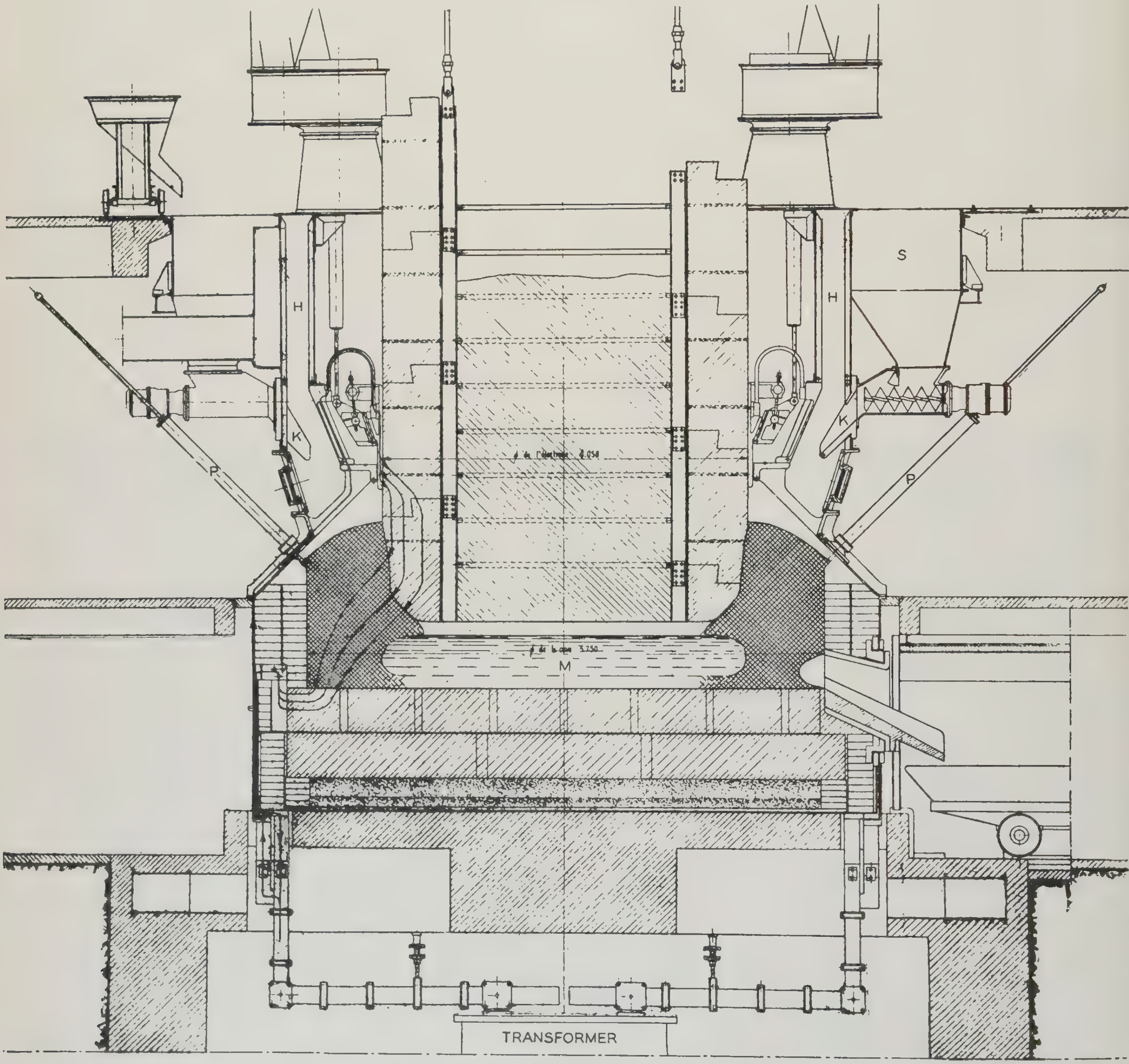


Fig. 2. Cross section of a 15,000-kw single-phase 50-cycle Miguet-Perron calcium carbide furnace, of the type shown in figure 1. Transformer (below furnace) rated 16,500 kva, 25/55 volts. Top of furnace, gas outlets, and upper end of electrode not shown (see figure 4)

H—Gas outlets *P*—Pokers *S*—Silos *K*—Hoppers *M*—Molten carbide

Use of Alternating Current or Direct Current

All this led, first to the combination of several plants by means of transmission lines, and then to the creation of networks in which all the producers operate in parallel, regardless whether their plants are hydroelectric or steam-electric plants. It is from these networks that the consumers—who are to a certain extent the producers themselves, especially the electrochemists and electrometallurgists owning waterfalls—derive the energy they require. The description of such networks is beyond the scope of the present article.

Such a principle leads readily to the production of alternating current (3 phase power being universally adopted), whereas many early plants with primitive installations operate with direct current. It is a well-established fact that it is nearly always advantageous to install alternators, even when direct current is utilized in the plant, as happens when aluminum, magnesium, sodium, chlorine, and its compounds are electrolytically produced. On some occasions direct current has been utilized for purely electrothermal operations; however, no noticeable advantage was derived from that practice.

With alternators it is possible to reduce the number of the generating sets; d-c machines cannot be built for comparable rates of power; the ratio is sometimes of an order of magnitude of 10 to 1. This leads to an appreciable decrease in the cost of the hydroelectric plant which needs less pipes, fewer valves, and discharge canals, etc. Certain hydroelectric plants with d-c machines contain up to 30 turbine-generator sets, while 3 alternators would have sufficed in installations built according to modern conceptions.

The efficiency of more powerful sets is appreciably higher; this applies to the turbine as well as to the electric generator and makes up, sometimes completely, for the loss caused by the necessary conversion into direct current. Because of these well-known reasons, the recent well-designed plants have been provided with alternators.

The transformation of alternating current into direct current is often accomplished by means of rotary converters which have a better efficiency than motor-generator sets. For instance, in a sodium chlorate plant thorough tests, which lasted several years, disclosed that the conversion from high voltage alternating current into 400 to 500 volts direct current took place at an efficiency of 92 per cent. This excellent result is due to the fact that the machines operated at full load without important variations, for more than $^9/_{10}$ of the time.

The direct voltage must be regulated, more or less depending upon the prevailing conditions. In practice, rotary converters permit a plus or minus 5 per cent regulation by means of their excitation, as an effect of added inductance or of high leakage transformers; the power factor remains about 92 per cent. Inasmuch as the starting takes place on the a-c side, the machines remain very simple, a very important point for the electrochemist who has sometimes more trouble with his electric equipment than with his electrolytic plant.

In some cases rotary boosters and starting motors are added to the rotary converters; also, voltage regulators have been installed between transformers and converters, and these voltage regulators require additional transformers when the primary voltage is too high. In general, all this complicates matters, reduces the efficiency, and it is just as well, if not better, to adopt under such conditions motor-generators which have at least the advantage of allowing any voltage variation desired.

Mercury rectifiers are little used, for in general the voltages required are low and the currents high, conditions which are not favorable to rectifiers. When prolonged high load operation is the rule, rectifiers will not improve the efficiency, or do so but very slightly. However, they have one advantage which is sometimes appreciated, they are noiseless. The progress accomplished in their manufacture will no doubt further their application in electrochemistry, especially if their price becomes somewhat advantageous.

Supplying Load From Power Systems

The success attained by the tying of electrochemical and electrometallurgical installations to general transmission lines to which they supply and from which they derive electric energy—thus becoming parts of a system which benefits everyone—has directed the attention of steam power plant operators to electrochemical manufactures, for the purpose of utilizing power during off-peak hours. For instance, plants for the production of calcium carbide have been so built. While the small 1,000 kw furnaces, which were in vogue in the year 1900, would not permit considerable power fluctuations which would entail serious temperature variations and thus interfere with production, modern furnaces of 10,000 kw and more can withstand power reduction lasting an extensive period of time and which, nevertheless, will not entail more than a moderate increase in the specific power consumption, while at the same time the purity of the product remains unaltered. This adaptability is partly due to their large weight giving an important heat reserve, partly to the relatively small heat losses through the furnace walls. It is possible to vary the voltage in the ratio of about 1 to 2, and also to alter the current. The result is that the producer of electric power has an apparatus at his disposal which allows fluctuations, amounting to thousands of kilowatts, sometimes in the ratio of 1 to 4.

The same results can be accomplished with other products. For instance, the electrolysis of sea salt has been considered, with the production of substances for industrial or domestic uses, such as liquid chlorine or hypochlorites, and the electrolysis of water.

Commercial considerations mainly hinder the development of such methods for regulating the power of large central stations. Consider, for instance, the production of calcium carbide. One can estimate that in France this industry absorbs, for local consumption and a certain amount of exports, approximately 600,000,000 kilowatt-hours per year. It will

be easily seen that only one large station of 100,000 kw capacity (a power which is often exceeded at present) which could supply an average of 20 per cent of that power, would devote to that purpose an annual energy attaining $^3/_{10}$ of the total energy absorbed throughout the entire country by the calcium carbide industry.

Many Applications in Smaller Industries

Power distribution systems in large cities and their suburbs have, nevertheless, to supply an increasing number of electrochemical and electrothermal installations. The electroplating industry, in which the individual installations are comparatively small but rather numerous, might be mentioned first. Also, the electric welding art must be included in that category.

The applications of electric methods in the foundry are becoming more and more important. The old furnaces for the production of bronze and other copper alloys, also cast iron, are being gradually superseded by the electric furnace. First, the arc furnace was utilized and later, with even greater success, the induction furnace with iron core, which is supplied at the normal network frequency and comprises a protruding heating loop (Schneider, Ajax, Weed, Russ). Because of this arrangement, the furnace has a much better power factor (ordinarily about 80 per cent) and a more favorable shape for the receptacle which is to contain the molten metal than the first models having only one large liquid turn or loop of molten liquid.

Large arc furnaces have also been installed in the vicinity of great cities, especially for the casting of medium and small steel parts. The capacity of these furnaces does not exceed, as a rule, 2 or 3 tons, and the power they absorb amounts to 1,000 kw, sometimes slightly less. With the electric furnace a large variety of steel castings can be obtained, the composition and the mechanical properties of which are maintained with precision. The prices of such castings can compete with the price of those obtained by means of rival methods. On the whole, the operation consists of the melting of scrap followed by some final treatment and requires scarcely more than 0.8 kw per kilogram of various castings ready to be delivered. The increase in cost above the cost of production by fuel burning furnaces—by means of which the operation would have been performed less perfectly—is small.

Induction furnaces, operating at a higher frequency, of the order of 1,000 cycles per second, are likewise utilized in smaller units. They permit very rapid fusion, a complete operation generally taking one hour and sometimes less. Because of these qualities the induction furnaces are sometimes adjoined to arc furnaces; with the induction furnace it is possible to bring rapidly to a high temperature a crucible which can be easily handled; this facilitates the production of small thin castings. They are also used to apply quickly to castings the metal which is necessary for the correction of defects, cracks, and blowholes.

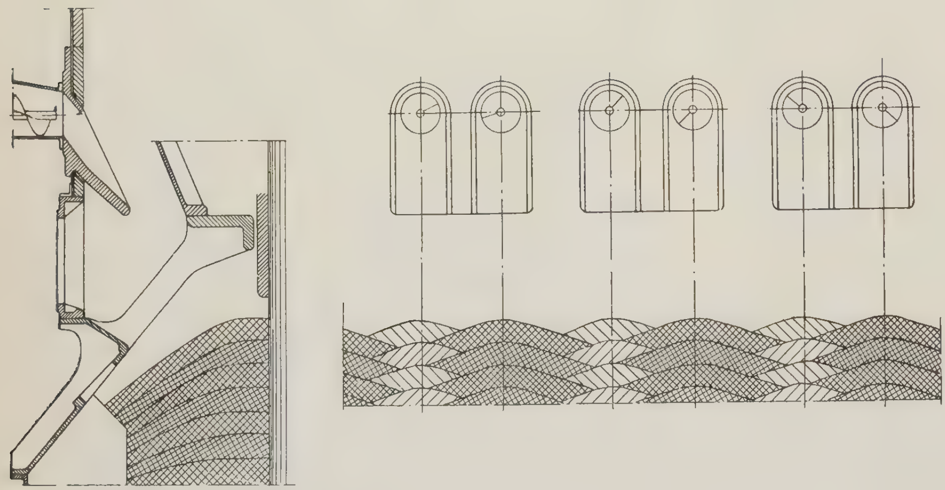


Fig. 3. Diagram of the distribution of lime mixed with coke and lime without coke, in the Miguet-Perron furnace

Cross-hatched areas represent conducting layers of 33 per cent limestone and 67 per cent coke; $7^1/_2$ turns of screw = 32 cubic decimeters

Lightly shaded areas in diagram at lower right represent layers of limestone; 3 turns of screw = 13 cubic decimeters

Note: Rate of feed varies with density and size of material

Consumption per metric ton of carbide: 855 kilograms limestone; 560 kilograms coke; 14 kilograms electrode

For the foundry operations mentioned hereinbefore radiation furnaces have been developed recently which consist simply of a rod of molded graphite which follows the axis of the cylinder constituting the furnace. The heating takes place at the normal frequency at about 20 to 30 volts and several thousand amperes. A value of 15,000 amperes has been attained with single phase current. One can also use several central rods, grouped for polyphase operation.

Calcium Carbide Furnaces

Consider, again, the large electrometallurgical and electrochemical industries. As a concrete example, attention will be given the furnaces used in the preparation of calcium carbide; these are quite similar to those which are used in the production of ferroalloys and abrasives, such as corundum and alundum. The dimensions of the apparatus which were used at the beginning of this century have been considerably increased, and enormous furnaces have been built recently, with the result that the specific energy consumption was reduced from 5 or more

kilowatt-hours per kilogram of carbide to 3 kilowatt-hours per kilogram.

For the 1,000 kw or 1,250 kva unit it was customary to use approximately 40 volts and 30,000 amperes, single phase current, generally at a frequency of 25 cycles per second, in some cases 50 cycles. With the advent of the more powerful furnaces, it became more difficult to obtain an acceptable power factor. The inductance of such a furnace can be easily estimated; it suffices to measure the mean perimeter of the loop formed by the furnace, i. e., its vertical electrode, its bottom electrode, the leads to their point of junction to a single bundle of suitably interlaced conductors, then to multiply that length by 4.8 (using the centimeter as a unit for the length as well as for the inductance). By multiplying by 10^{-9} and $2\pi f$ (f = frequency) one obtains the reactance in ohms. When the power of the furnace is increased without changing its general design, the reactance increases so that the reactive voltage, which is obtained by multiplying again by the current, attains the above-mentioned 40 volts and exceeds that value.

Two schools of thought of entirely different trends have found adherents: one school has followed the tendency to retain 40 volts or little more. In order to obtain this result, the loop dimensions had to be reduced as much as the service of the furnace and the operation of the electrode would permit, but this soon became insufficient. To overcome this difficulty, the following solution was worked out: an upper movable electrode was supplied by means of several loops operating in parallel, but running in different planes so as to have the lowest possible mutual induction. With this arrangement the reactive voltage will scarcely exceed that which corresponds to only one of the loops carrying its own current. The Miguet-Perron furnace constitutes a brilliant solution of these and many other engineering difficulties. In some of these furnaces the power can be varied by regulating the voltage from 25 to 55 volts, the current attaining several hundred thousand amperes (up to 400,000 amperes was attained in one particular furnace). Such large furnaces range from 5,000 to 16,000 kva capacity, and operate always with one single vertical electrode. These furnaces are usually combined in pairs on a quarter-phase secondary circuit. The power factor at the normal network frequencies is around 90 per cent and even higher.

According to the other school, the voltage was increased: at about 40 volts the furnace operates mainly as a resistance furnace, the resistance consisting of the molten carbide and a relatively small amount of extremely hot substances directly above it; but if the upper electrode is pulled up, successive arcs are formed between pieces of the charge going into reaction. Hence a deeper furnace is required, of somewhat different construction, since the distance between the vertical electrode and the bottom attains sometimes 1.8 meters instead of a few decimeters as in the old apparatus. Ordinarily, with this arrangement of deep furnaces the 3 operating zones are combined within 1 single apparatus under the 3 vertical electrodes of a 3 phase system, and then the furnace has no true bottom electrode but simply a neutral point which carries no current when the 3 star-connected arcs are well balanced.

Three Phase and Single Phase Calcium Carbide Furnaces

From the purely electric viewpoint the 3 phase furnace has the advantage of reducing the currents and thus the difficulties entailed by the enormous currents. For equivalent operating conditions the power per 3 phase unit with 100 volts per electrode (173 volts between electrodes) and 33,000 amperes is the same as with one 40-volt 250,000-ampere single-phase furnace. It is certain that in the second case the difficulties to be overcome by the transformer designer and those caused by stray currents are greater.

There is practically unanimous agreement as to the advantage of concentrating the heat in a zone of small volume for obtaining a very pure carbide (the highest possible power per unit volume of zone) and this is the main argument of the partisans of retaining the single phase furnaces and the low voltage. However, the 3 phase furnace has made considerable progress, and to cite an example, the new 12,000 kw apparatus of the "Société des Produits Azotés" produces, with a specific consumption of 3 kilowatt-hours per kilogram, carbide yielding 300 liters of acetylene per kilogram, the voltage between the electrodes amounting to 165 volts and dropping sometimes to 100 volts. The consumption of ready-made electrodes or of paste for Söderberg electrodes ranges with this type of furnace from 10 to 15 kilograms per ton of carbide. The above-mentioned degree of purity of the carbide, which corresponds to 86 per cent of calcium carbide, is usually deemed sufficient for the production of acetylene as well as of cyanamide. It is very possible that better results may be obtained with single-phase low-voltage furnaces, should a higher degree of purity of carbide be required.

The collection of the valuable carbon monoxide is no doubt easier in single phase furnaces, and the Miguet-Perron furnaces accomplish this task quite successfully. However, the 3 phase furnace also now permits the collection of a fair proportion of the carbon monoxide, 50 per cent at times and even more, according to certain authorities.

One detail which differentiates the 2 extreme types of furnaces is the formation of vaults which prevent the material of the charge from advancing to the zone of reaction. These vaults must be broken; formerly, they were broken through manual labor by means of pokers; in the Miguet furnaces this difficulty has been very cleverly overcome by means of a somewhat complicated pneumatic device which pokes the vaults. Builders of large 3 phase furnaces have now succeeded in entirely eliminating the necessity of breaking up the vaults, for in some 3 phase furnaces the distance between the electrodes and walls of the chamber is sufficiently large to prevent their formation.

In conclusion, it may be stated that the adherents of both systems vie with each other in the creation of ingenious devices, and it is impossible to attribute general superiority to either system.

The Miguet-Perron Furnace

There will now be discussed a few points concerning the large single phase furnaces of the Miguet-Perron type. (See figures 1 and 2.) In these furnaces the transformer is placed underneath the furnace, and it is equipped on the high voltage side with an automatic voltage regulator with tap changing under load. The low voltage current is conducted along the furnace by a certain number of interlaced or transposed bars reaching up to the bottom of the furnace. A metallic wall around the brick casing is double and consists, in the large furnaces, of 2 bronze cylinders 10 centimeters apart, insulated one from the other. The bars, for each of the polarities, are connected to their respective cylinders.

The internal cylinder is connected to plates sealed to carbon blocks acting as the bottom electrode. The upper part of the external cylinder has an extension in the shape of a truncated cone which surrounds the electrode and bears flexible leads. These leads terminate at the contact plates on the electrode, the number of which, distributed around the furnace, may reach at times 48. As a first result of this arrangement the furnace can be closed better and gases easily collected.

The external cylinder, as well as the electrode, is grounded, and this constitutes a considerable advantage, not only as far as the fabrication and the control of the electrode are concerned, but also as regards all the furnace operations in general. (In a 3 phase furnace the electrodes must be insulated one from another, and it is the bottom which is grounded.)

The continuous electrodes of Miguet-Perron furnaces consist of a peripherical part, which is progressively built on top of the electrode so as to compensate for its wear, and consists of sector-shaped prebaked carbon blocks, carefully adjusted, the clearance ranging between 0.5 and 2 millimeters. These sectors are dovetailed, and the joints are lined with an appropriate paste. The cylindrical interior of the electrode is filled from time to time by a cheap paste consisting of coke powder and tar, rammed by pneumatic hammers. The electrodes for 400,000 amperes have an outside diameter of 4.05 meters, and the carbon wall is 65 centimeters thick.

The use of such large electrodes bring up a special question with reference to the use of this furnace for the production of calcium carbide. With a resistivity of 5,000 microhms-centimeter (microhms per centimeter per centimeter square) at 50 cycles the skin effect reduces the effective peripheral thickness of the conductor to 50 centimeters (a little more because of the contacts of the fabricated electrode). Thus the core of the electrode serves only as a support for the peripheral blocks. This is true only at some distance from the extremities of a long electrode. At the ends, if connection is made to another conductor having a much higher resistivity (and not giving rise to such pronounced peripheral concentration of current) the current distribution is extended to near the center of the electrode at the plane of contact. In the case under consideration the bath of molten carbide has a resistivity much higher than that of the electrode (it requires a higher voltage for a much shorter length). As a result, the effective resistance is lessened and the zone of reaction is not so much diminished by the skin effect in the electrode.

The problem thus stated is interesting from a theoretical viewpoint. Practically, the inventor of the furnace considers that this current distribution over the face of the electrode is unfavorable (especially with such large electrodes) as it would superheat the already made carbide at the center of the bath with the effect of partial dissociation. This result is prevented by maintaining a small gap between the face of the electrode and the bath (see figure 2).

The large part of the current flows from the external cylindrical surface of the electrode through the incoming charge, as indicated by the arrows in figure 2. This requires a higher electrical conductivity of the charge than is general in calcium carbide furnaces, and this degree of conductivity is obtained by the use of a special coke in small pieces and by regulating the proportions of carbon and lime in the charge as it comes from the different hoppers. Thus the charge as it reaches the path of the current consists of a controlled distribution of layers with a small proportion of lime (for high conductivity) and complementary layers of lime only, as shown in the diagram of figure 3.

The inductance affecting the power factor is determined by 4 times the measure of the surface between the internal conducting wall, the flexible leads and the length of the average path of current flowing in electrode and charge, divided by its average diameter. Even in the largest furnaces this surface is very much reduced (a few square meters) and the power factor attains 90 per cent and sometimes up to 95 per cent. Exterior views of Miguet-Perron calcium carbide furnaces are shown in figures 1, 4, and 5.

Production of Aluminum

Take another example, that of an industry which, in France, consumes approximately as much energy as the calcium carbide industry; namely, the production of aluminum. Here the size of the furnaces has increased to a lesser degree. The voltage cannot be raised, since it is determined by the electromotive force required for the electrolysis, plus the voltage drops which every one strives to decrease. As regards the current, it has increased from 10,000 amperes or a little less, to 20,000 amperes or a little more; but this does not apply to all plants, since many of them have retained an equipment which was designed only for 10,000 to 15,000 amperes. Some pieces of apparatus operate at a higher current but rather in an experimental way. Finally, 100 kw per furnace is scarcely exceeded, and frequently even this figure is not attained.

From the chemical viewpoint the operation is always the same; alumina is dissolved in molten salts, the flow of direct current carries the aluminum to the bottom which is connected to the negative pole. As regards the composition of the bath, there is a tendency to simplify it, and the addition of divers

chlorides and fluorides (sodium, calcium) have not as many advocates as formerly, and cryolite or a double fluoride of aluminum and sodium of similar composition is more often used. These last substances melt at a higher temperature than certain other mixtures, but give rise to less evaporation and introduce fewer impurities. A certain diversity of ideas is apparent, within narrow limits, however, so that the operation of the furnaces and their output are not greatly affected thereby.

The natural Greenland cryolite has been supplanted to a considerable extent by artificial cryolite which is purer. In that bath the alumina is dissolved in a proportion generally attaining a maximum of 15 per cent, is reduced by electrolysis, and must then be re-established, etc.

The method of extracting pure alumina has changed little: bauxite with as little silica as possible is treated in digestors by a concentrated soda solution which is filtered, diluted, and stirred so as to cause the alumina to settle, then again concentrated and so on, according to Bayer's process. The presence of silica in the ore has the effect that a complex precipitate loses alumina and soda; its composition is rather variable, it has been found, for instance, that 1 part of silica will make insoluble 0.85 part of alumina and 0.8 of soda which are thus lost. Titanic acid acts in the same manner but about $^1/_5$ as much.

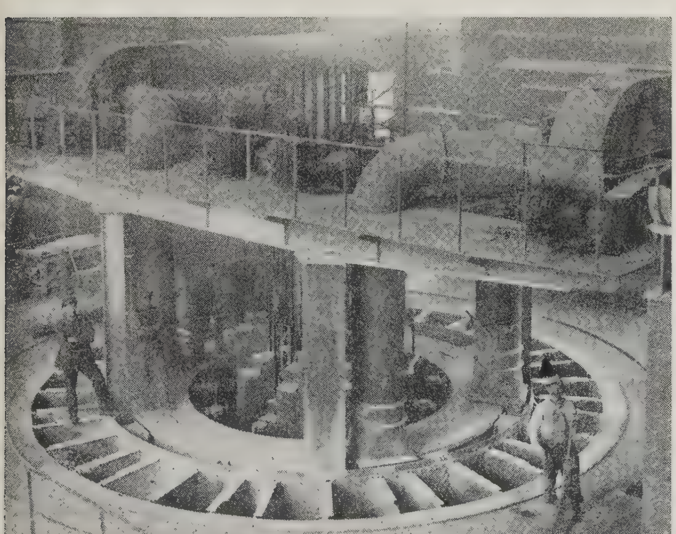


Fig. 4. The 16,000 kva Miguet-Perron calcium carbide furnace shown in figure 1. Top of furnace showing upper end of electrode and gas outlets

With certain disadvantages, among which are these losses, one can treat bauxite and other ores containing more silica and existing in inexhaustible quantities. However, it is quite understandable that the first treated bauxites had 2 to 4 per cent silica, containing generally more than 20 per cent ferric oxide which is less disturbing. In certain regions this material is becoming rare, but in others, such as British Guiana and India, it is still encountered in large quantities.

Alumina as obtained by the Bayer process has a purity which has never been exceeded and even reached by other methods; it amounts to 99.5 per cent and over in regular production.

More recent research aims at the utilization of the ores of lower grade more frequently encountered, such as certain clays, treated by means of sulphuric and nitric acids, which have been combined to processes of the fixation of atmospheric nitrogen, and of the production of ammoniacal or nitric salts for agricultural purposes.

The Aluminum Nitride Process

It would seem apposite to call attention again to Serpek's aluminum nitride process, the industrial exploitation of which 20 years ago was considered a failure, notwithstanding the ease with which the reaction can be obtained on a small scale. The ore, which can be a rather siliceous white bauxite, is treated in the electric furnace with carbon in a nitrogen stream. Above 1,800 degrees centigrade the alumina reduction takes place with the formation of carbon monoxide, the aluminum combining immediately with the nitrogen. The product obtained from the furnace, which in regular commercial production could contain 18 per cent of nitrogen, can be easily treated with soda in a simplified Bayer plant producing ammonia and alumina.

Some investigators are of the opinion that the difficulties which have been encountered could now be overcome, and that the process could be applied as far as its technical aspects are concerned, successfully, in view of the considerable progress which has been made in the construction of electrothermal equipment.

It would be necessary to furnish approximately 16 to 18 kilowatt-hours per kilogram of nitrogen contained in ammonia, that is to say, nearly the same amount that can be obtained by water electrolysis and the compression of hydrogen with nitrogen derived from liquid air. The process involving the carbide and calcium-cyanamide gave similar results, though at present the large apparatus which has been discussed in the preceding section allows the energy consumption to be reduced to approximately 10 kilowatt-hour per kilogram of nitrogen. The alumina which is obtained by the aluminum nitride method would, in this manner be a by-product, at least partly, and could be included in estimates at a rather low cost.

Electrothermal Production of Aluminum

Attempts have been made to eliminate the purely chemical part of the manufacture of aluminum by treating the bauxite or similar ores in arc furnaces until fusion, and bringing about the separation of impurities by the addition of carbon. This addition causes the reduction of oxides of iron, of silicon, of titanium, also a part of the alumina in the form of a complex alloy which is separated by tapping. On the whole, it is the application of the process by means of which abrasives, such as corundum and alundum which are crystallized impure alumina, are obtained; this process has been known for more than 40 years. For the aluminum manufacture, the

highest possible degree of purity is aimed at, but so far not very favorable results have been attained from that viewpoint, although the process has been sometimes conducted until a second fusion, which is rather expensive. Another disadvantage is that the product is hard to crush and dissolves less readily in cryolite than alumina chemically obtained. The lower degree of purity influences the metal. It has been proposed to purify that alumina by means of a stream of hot chlorine which would volatilize the main impurities.

An improvement consists in transforming the alumina into aluminum sulphide by introducing iron sulphide into the arc furnace (Haglund process). The aluminum sulphide thus obtained melts at 1,000 degrees centigrade and dissolves alumina. The product, when treated with water, produces alumina and hydrogen sulphide which can be used for reproducing the iron sulphide. The consumption in electric energy is reduced to 75 per cent of the amount required by the simple arc process. Moreover, the alumina is purer, although it does not quite attain the quality obtained with the Bayer process. The Haglund process is applied in an Italian plant.

Electrical Quantities Involved in Producing Aluminum

The electrolytic operation of producing aluminum, constituting in itself a reaction or sum of reactions, consists in decomposing the alumina into metal and into oxygen which burns the carbon of the electrode. From there, the dissociation voltage will amount to 2.79 volts if the oxidation of the carbon is not supposed to intervene, 2.22 volts if that oxidation produces carbon monoxide, and 1.76 volts if it produces carbon dioxide. As a matter of fact, the gas issue from the electrodes is a mixture of carbon monoxide and carbon dioxide. Theoretical questions are here arising which have not been perfectly clarified as yet.

The voltage is increased as a result of secondary effects (some of which are not quite well defined), and because of the resistance of the bath. Toward 950 degrees centigrade the ordinary cryolite baths, or similar mixtures of sodium fluoride and aluminum fluoride, and about 15 per cent alumina, have a resistivity of 0.55 ohm-centimeter, which drops somewhat when the temperature rises. Certain additions, now less frequently used, such as calcium fluoride, lower the resistivity toward 0.4 ohm-centimeter, but then the bath will dissolve the alumina with more difficulty and its density will be increased, a feature which impedes the separation of the metal.

According to Faraday's law, one kilogram of aluminum is produced with 2,980 ampere-hours. In practice, the yield is somewhat lowered by several secondary effects, and especially by the oxidation of the aluminum already formed, remaining in small drops in the bath, whose density differs little from its own. These aluminum droplets are encountered by the oxygen traveling toward the anode, and are oxidized again. Practically, 3,720 ampere-hours are sometimes required with the yield dropping to 80 per cent, and up to 3,975 ampere-hours with a yield of only 75 per cent.

The theoretical consumption calculated with 2.22 volts would be 6.6 kilowatt-hours per kilogram of metal. Practically, much more is needed, and the performance barely attains an energy efficiency of 30 per cent (always assuming a theoretical electromotive force of 2.22 volts).

The figures which have been published are much at variance; sometimes they are influenced either by pessimism or optimism, but they are often the result of appreciable errors in measurement. The first plants with d-c generators were usually not provided with apparatus for measuring the current and the power which were accurate and not influenced by the magnetic fields due to the intense adjacent currents. Moreover, one must bear in mind that some authors speak of the yield of the furnace, properly speaking, while others consider also the conductors between furnaces and to the machines. It is also necessary to introduce the effect of discontinuous operations, and of the stops, a very important factor as has already been indicated. This explains the variety of opinions concerning the progress which has been achieved.

As a matter of fact, since anodes of rather large cross section are generally used (over 30 by 30 centimeters and in small numbers), the current density dropping to one ampere per square centimeter, not

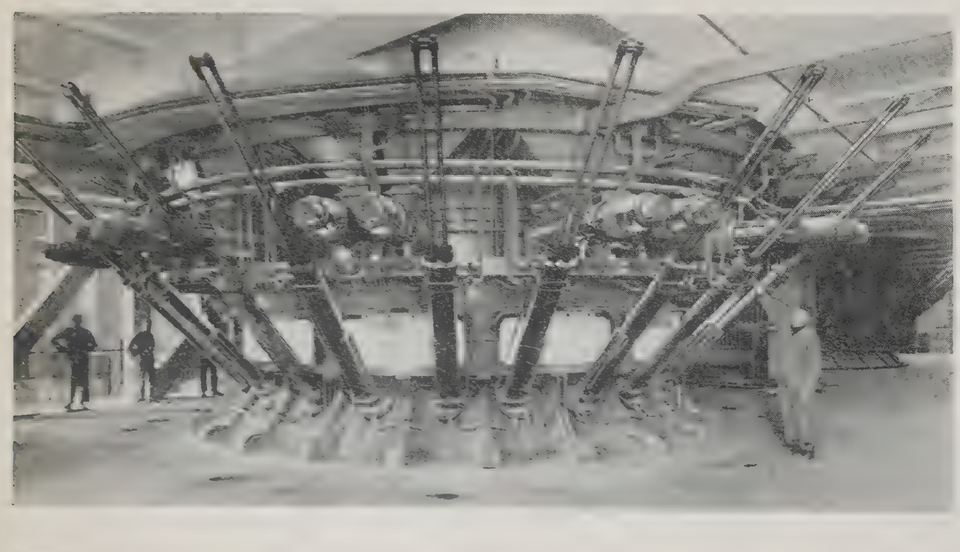


Fig. 5. Second floor view of the furnace of figure 1 showing the air driven pokers and the motor driven screw feeds

much progress has been accomplished as far as the power consumption is concerned, except on one point: the losses through the bottom of the hearth.

Even before 1900 the consumption required in furnaces designed by Heroult was little less than 25 kilowatt-hours per kilogram. Surveys conducted in 1910 in a number of well-equipped plants give similar figures, some a little lower. A large project, which had been worked out at that period for installations to be operated with 3-phase high-voltage current called for 30 kilowatt-hours per kilogram, including the transformation of current and other items, such as the various motors, among them those required for the manufacture of electrodes and the hoisting and conveying apparatus. In this case the plants were to receive their power with considerable fluctuations, and that alone would give an appreciable increase above the figure which could be obtained with a fixed amount of power. In this manner the series of 10,000 ampere furnaces with well-designed connecting bars and good electric contacts would have absorbed, in steady operation, approximately 25 kilowatt-hours per kilogram.

Present-Day Electrical Consumption

What figure has been reached today? The losses through the bottom of the former furnaces were far too high. It was then customary to use a cast iron or steel bottom plate and to cover it with a mixture of carbon powder and tar compound. This mixture was baked during the first operating period, and in this manner had a resistivity attaining 5,000 and even 10,000 microhms-centimeter, that is, respectively, $^1/_{200}$ or $^1/_{400}$ of the conductivity of hot iron. However, the heat conductivity remained about the same as that of iron or only a little less. As result with such an arrangement, a thin layer of carbon will limit the electric losses considerably, but it will allow a large quantity of heat to escape which is withdrawn from the bath, to such an extent that the bottom plate may become red hot and thus imperil the electric contact. In order to reduce the temperature of the bottom plate under these conditions, the thickness of the carbon lining had to be increased, beyond 40 centimeters at times, and then its electric resistance became too high. Formerly it was considered that a voltage drop of one volt between the metal bath and the incoming negative conductors was a good result notwithstanding the fact that this corresponded to a supplementary supply of 4 kilowatt-hours per kilogram of aluminum. Indeed, since more than 20 years ago, this point was taken into consideration. By lowering the voltage drop to 0.5 volt without increasing the heat conductance, 2 kilowatt-hours per kilogram can be gained and still more if the heat conductance is reduced as much as possible.

A scheme, which is frequently adopted, consists in using rather thick carbon blocks, prepared as are electrodes, which are placed on the bottom plate; cast iron is then poured between the blocks so that it will reach the bottom plate and after its solidification will combine the entire system into one solid block. The lower surface of the bottom plate is provided with heat insulation; nevertheless the part which projects outside the furnace, where the negative conductors are connected (steel is copper plated at times), may still become too hot.

A better construction is to provide each one of the carbon blocks with an iron rod which is preferably sealed by pouring cast iron just as in the case of the anodes. These bars are fastened to the bottom plate by means of suitable nuts which insure sufficient electric contact. The lower part of the blocks is separated from the bottom plate by a lining which constitutes a good heat insulation and through which the iron rods pass. In addition to this, cast iron may be poured between the blocks so as to unite the whole very solidly.

The increase of the rated current reduces somewhat the specific consumption, for the relative lateral surface of the furnace decreases slightly. The changeover from 10,000 amperes to 20,000 amperes brings a slight gain of scarcely one kilowatt-hour per kilogram.

A cross section of a 20,000 ampere aluminum furnace is shown in figure 6.

Several pieces of apparatus as described in the foregoing paragraph, rather similar in design, have been put in service by various manufacturers. These furnaces, of 20,000 amperes capacity on an average, will consume 22 kilowatt-hours per kilogram at constant power (including the connections) with 3,700 to 3,800 ampere-hours per kilogram and a voltage of 5.8 to 6. Sometimes a lower voltage can be obtained by placing the anodes closer to the bottom, but this causes a slight increase in the ampere-hour consumption, for some of the liberated aluminum swimming too near the anode oxidizes, especially when the distance between the anode and cathode becomes less than about 6 centimeters. A consumption amounting to a little less than 22 kilowatt-hours per kilogram can be arrived at, in average commercial operation by careful tending and supervising. Is it possible to attain 20, or even less, as some have claimed? This is the best which seems obtainable with modern furnaces, whose general conception dates back 40 years.

There remains little whereby these results could be improved. One could try to decrease the voltage between terminals by further decreasing the current density in the anodes, which at present has been brought down to approximately one ampere per square centimeter. But in order to maintain the necessary temperature—without appeal to a supplementary heating by coal or gas, already mentioned by Hall and Heroult—the heat losses must be reduced; most of these originate from the upper surface. It must be remembered that in the conventional arrangement the upper surface must be free and that room must be left for the regulating, the changing of the anodes, the introduction of alumina, and the agitation of the bath. The heat losses, originating from the upper surface, correspond from 8 to 10 kilowatt-hours per kilogram of aluminum produced. These high losses have led to the construction of closed furnaces, some of which, involving the use of removable walls, have been already built. Some designers would like to go one step further and surround the apparatus with a permanent vault accompanied with mechanical devices that would

insure automatic operation and especially an alternating motion of the anodes which will now be discussed.

Control of the Anode Effect

The dissolution of the alumina in the bath is rather slow. In the early models the round furnace rotated around a vertical axis, and the anodes remained stationary. The negative pole was connected to a contact in a mercury pool. This arrangement produced a permanent agitation, favorable to the dissolution of the alumina which was constantly added to the bath. When the current was raised, this arrangement had to be abandoned. The dissolution of the alumina must be facilitated by stirring the bath from time to time with rabbles, but without entirely preventing the disagreeable "anode effect." As soon as the bath contains too little alumina, its resistance increases, the gases caused by the reaction gather under the anodes, and the furnace (which forms a part of a series to which a constant voltage is applied) absorbs, instead of 6 volts, up to 15 volts, 30 volts, and more; this in turn creates excessive heating and the well-known trouble entailed thereby. For this reason much importance is attached to the transversal dimensions of the anodes which must not exceed certain limits. Tests which were conducted about 1910 have proved that it is scarcely advisable to go above 40 centimeters in one dimension; in 20,000 ampere circular furnaces built in 1912 the electrodes had a trapezoidal section (dimensions 60 by 40 by 10 centimeters) to provide outlets for the escape of the gases. At the same period a design for a square furnace with electrodes of 65 by 65 centimeter section was rejected because of these large dimensions.

It seems that these results have been all forgotten, as 15 to 20 years later furnaces with one single Söderberg electrode of 1.6 meter diameter made their appearance; these furnaces operated rather poorly, their voltage rose at times up to 80 volts, the escape of the gases from the anode surface being very difficult.

The use of continuous electrodes in a furnace, whose losses everybody insists should be reduced, seems rather debatable. The "lost heat" must be rather suppressed than utilized. But perhaps there may be some compromise in special rare cases.

The anode effect can be very much lessened by some stirring which aids the displacement of the alumina. For many years various devices to this end have been discussed, such as an alternating rotation of the furnace or the alternating displacement of the anodes (planer motion), the effect of which could be improved by inclining the anodes or by giving them a cross section in the shape of a parallelogram. Also an auxiliary alternating current has been advocated which would flow through the bath at right angles to the direct current producing the electrolysis. So far all these arrangements have found little application in practice. It might be worth while to give them again due consideration.

It is a well-known fact that the direct current is interrupted in a liquid bath when the aluminum is the anode and receives oxidizing ions. The following question arises: if an aluminum bath is supplied with alternating voltage preferably of low frequency, will the current appear only in the direction required by the electrolysis? If that were possible it would render the transformation of alternating to direct current unnecessary. It has been found by experience that this does not happen, and this might be foreseen for the alumina layer which is produced on the aluminum anode is too rapidly dissolved.

Other Uses of Igneous Electrolysis

Magnesium is also obtained by means of igneous electrolysis, but so far, little success has been made by the decomposition of magnesia dissolved in appropriate baths. Certain fluoric baths have been proposed; however, these baths have the disadvantage that they dissolve too small a proportion of oxide; moreover they are expensive. For this reason, the chloride is generally electrolyzed, but this process has the inconvenience of generating chlorine, a noxious gas which requires closed apparatus. Chlorine is used for the reproduction of chloride, for the ores conduct to the oxide or magnesia.

It may be mentioned that in the electrolysis for the production of sodium, one has the choice of electrolyzing sometimes the oxide, at other times the chloride. The latter, common sea salt, is much less expensive but requires another industry operating conjointly which will absorb the chlorine.

The size of the furnaces for the production of magnesium has considerably increased. The same principles which are applied to aluminum cells have made it possible to come closer to the theoretical consumption which corresponds to the decomposition of magnesia requiring 6.9 kilowatt-hours per kilogram with a theoretical electromotive force of 3.1 volts. Certain apparatus has been described which operates at about 7 volts and consumes about 20 kilowatt-hours per kilogram, corresponding to an efficiency of about 80 per cent as regards current and of about 34 per cent as regards energy.

It is to be feared that whatever improvements can be made in igneous electrolysis will lead only to a rather mediocre efficiency. This is the common fate of much apparatus operating at low voltage and high current, whose losses will never go below a certain limit. From a certain point which is now nearly reached, any improvement in the efficiency entails a relatively high cost which is sometimes prohibitive.

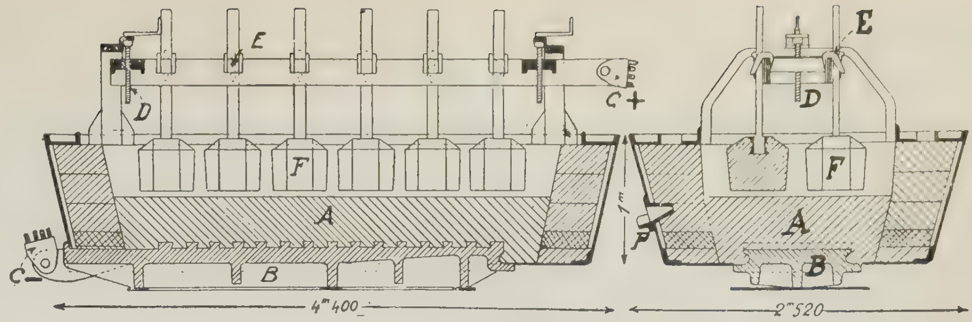
Does this mean that other processes must appear for obtaining metals such as aluminum and magnesium? This goal is perhaps not beyond reach considering the progress and improvements made in industrial electric heating, which were not thought of when other processes were abandoned for electrolysis.

Aqueous Electrolysis

A few words may be added regarding aqueous electrolysis. The decomposition of water was developed to a great extent because of the demand for pure hydrogen, which is mainly used for the production of ammonia (by compressing it with nitrogen). Very

Fig. 6. General arrangement of 20,000 ampere aluminum furnace

A—Carbon lining
B—Bottom plate
C—Terminals
D—Screw for vertical movement of all electrodes
E—Individual adjustment of electrodes on positive bus
F—Electrode
P—Spout



large plants have been started. In France one of these plants comprises a converter station aggregating 26,000 kw.

The electrolysis of sea salt for the production of chlorine or chlorates (depending upon whether a diaphragm is introduced or not) has attained a state of perfection where only details are subject to some improvements. One striking point may be mentioned in particular: the question of decomposing the chlorate which was already formed by the hydrogen produced at the cathode, which decomposition formerly reduced the current efficiency to 30 per cent at times, has been solved by adding to the bath small quantities of substances, especially bichromates; as a result of such a small change the current efficiency regularly reaches nearly 80 per cent.

It is always interesting to mention applications which represent progress realized in other industries. Thus, in the production of sodium chlorate, one obtains a solution containing approximately 100 grams of chloride and 450 grams of chlorate per liter, and it is necessary to extract the major part of the latter salt, and to return the liquor to the circuit after having brought the quantity of chloride to 280 grams per liter. Formerly $^2/_3$ of the water was evaporated. While the chlorate is very soluble in hot water, the solubility of the chloride is practically independent of the temperature, and thus the chloride would be deposited during the concentration and the chlorate during the cooling. In this manner, the expenditure of coal amounted to 0.5 kilogram per kilogram of chlorate obtained; the progress accomplished in the refrigerating industry has made it possible to cool the liquors below zero degrees centigrade economically. The chlorate which is not very soluble in the cold state, especially when the liquor contains chloride, is deposited alone; the coal expenditure is quite eliminated and the power consumption of the motors driving the refrigerating machines has been made only one per cent of the power required for the electrolysis, amounting to about 0.07 kilowatt-hour per kilogram of chlorate.

Choice of Voltage

The choice of voltage is very important to the electrical engineer. In general, it is preferred to apply a voltage which, though remaining moderate, will be as high as the apparatus and lines will warrant. The increase in power of the installation justifies this tendency more and more.

The arc furnaces for the production of steel have passed from 40 volts and 100 volts to 250 volts and beyond with good results. It is common practice to use 3 phase current with the neutral grounded. The workmen very seldom need to come into contact with the electrodes.

The induction furnaces comprise circuits of 2,000 volts and more, with a separation of only 4 to 5 centimeters between the conductors and the molten metal. Also these circuits are so located that the operators are likely to come near them. Will this apparatus, when used in large numbers, entail the trouble feared by certain experts? It must not be overlooked that, with certain precautions in the design, it is possible to build low voltage apparatus.

The igneous electrolysis of alumina is accomplished by connecting the furnaces in series up to 500 volts and beyond. It suffices to place the 2 ends of the battery of furnaces far enough apart to avoid any danger.

Also in the aqueous electrolysis a potential of 500 volts has been attained, even in those plants where the operating personnel has to perform certain operations with live parts. In these installations the middle is grounded and precautions as regards insulation are taken which have been shown in practice to be sufficient.

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Load Losses in Salient Pole Synchronous Machines

The short circuit test of a salient pole synchronous machine in which rated armature current is being circulated is conventionally used for determining the load loss. In certain cases, it is necessary also to know the load losses when the machine is operated at rated conditions of voltage, current, and power factor. Methods for predetermining the short circuit losses are given in detail in this paper, and the results of calculations are presented. Methods of predetermining the losses under rated conditions are given briefly.

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Membership Application Pending

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THE segregated loss efficiency of a synchronous machine is demonstrated using losses obtained from tests performed in accordance with accepted test procedure. The component losses are friction and windage, no load iron loss, armature copper loss, field copper loss, and load loss. The copper losses are based upon the d-c resistances of the respective windings. The A.I.E.E. standard test for load loss is performed by operating the machine on short circuit with rated armature current. Then the load loss is defined as the total shaft input minus the friction, windage, and armature copper losses.

In order to predetermine the conventional load loss, it is necessary to study conditions existing within the machine during operation on short circuit. The alternating armature slot leakage flux, resulting in eddy currents in the armature copper, is the most obvious source of load loss. The eddy currents cause a copper loss in addition to that represented by the d-c resistance which is generally the largest single component of the short circuit load loss. The magnitude of this loss may be determined mathematically.

The magnetomotive force of the armature winding as distributed in the air gap may be regarded as composed of a sinusoidal fundamental, a series of phase belt harmonics due to connecting the winding in definite phases, and a series of slot harmonics due to concentration of the current in a finite number of slots.

During the short circuit test, the fundamental armature magnetomotive force is practically directly opposed to the field winding magnetomotive force. The latter is not distributed sinusoidally in the air gap. The resulting differential flux is a source of losses in the stator teeth and supporting end fingers. These losses are not a very large part of the total conventional load loss, except in machines of unusual design.

The phase belt and slot harmonics produce fluxes resulting in losses in the pole face and the damper winding. These losses may be predominant in low speed machines with short air gaps and high resistance damper bars. The phase belt losses are quite large in 2 phase machines under certain conditions.

Although the flux paths in the end zones are principally through air, appreciable flux densities can exist in adjacent iron parts due to currents in the end windings. This is partly due to the ineffectiveness of the field magnetomotive force in opposing that of the armature end winding and partly to the relatively small areas of the flux paths in the solid iron parts. The end bell and end plate losses are of importance in machines of large pole pitch.

When the machine is operated at rated conditions of voltage, current, and power factor, a high peak density appears at one edge of the pole, the magnitude of which is reduced by saturation of the stator teeth and of the pole tips. The peak density results in larger losses in the stator teeth and associated parts and in increased pole face and damper winding losses.

Eddy Current Loss in Armature Copper

The most obvious source of loss is the armature slot leakage flux which causes a nonuniform distribution of current in the armature winding. Although the combinations of strands and conductors in the armature winding may become complicated, the distribution of flux density across the armature slot is simple and the loss resulting from eddy currents may be determined mathematically. This has been done by Gilman,[1] whose formulas were used in calculating this component of the load loss in the examples of table II.

In addition to eddy currents arising from flux distribution in the slot, another type of eddy current is found in the end portions of the coil. Current in the end windings produces a flux density in the end zones having a component approximately perpendicular to the plane of the windings. This gives rise to eddy currents flowing along one side of each strand and returning along the other side. No attempt has been made to calculate the resulting loss. Allowance for this loss may be made quite roughly by assuming the strand loss in the end portions of the coils to be the same as in the embedded parts.

Losses Due to Air Gap Flux Distribution

The magnetomotive force of the armature winding as distributed in the air gap may be regarded as com-

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1. For all numbered references, see list at end of paper.

posed of a sinusoidal fundamental, a series of phase belt harmonics due to connecting the armature winding in definite phases and a series of slot harmonics due to concentration of the current in a finite number of slots.

Losses Due to Fundamental of Armature Magnetomotive Force

The power factor of a synchronous machine operating on short circuit is approximately zero. Only polyphase machines, in which the fundamental of armature magnetomotive force rotates synchronously with the field, are considered herein. The maximum of the armature magnetomotive force fundamental occurs approximately at the pole center line and opposes the magnetomotive force of the field. In salient pole machines the latter is distributed as a rectangular wave at the air gap. The resultant magnetomotive force sets up a flux in the air gap which, though very much distorted, must contain a large enough fundamental to induce a voltage in the armature winding equal to the armature leakage reactance drop. A large third harmonic is also present so that the total flux wave has high peaks near the pole tips and a minimum value, which may be negative, at the pole center line. This is illustrated in figure 1.

Since both field magnetomotive force and armature magnetomotive force fundamental rotate synchronously, the resulting flux cannot produce loss in the field member. The flux wave cuts only the armature and because of its peculiar shape and high peaks, is a source of loss in the armature teeth and supporting end fingers.

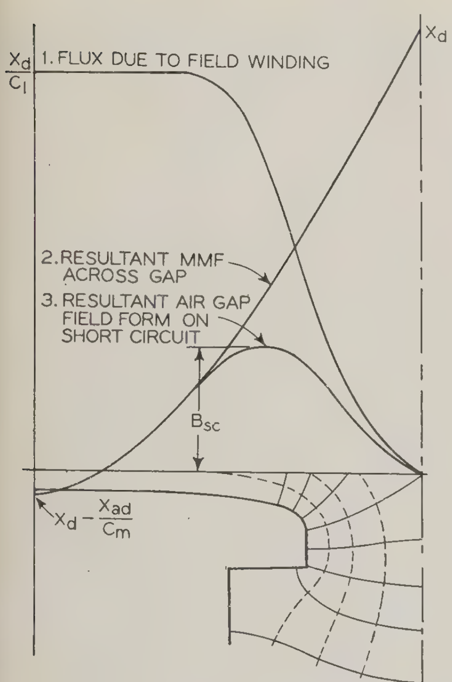


Fig. 1. Flux map of synchronous machine on short circuit, and corresponding distribution of flux density along stator surface

In the "per unit" system of notation used herein, rated voltage and current are considered as unit voltage and current, respectively. (In the "per unit" system, 1.5 per unit, for example, corresponds to 150 per cent in the more usual system.) Since only the condition of rated or unit current on short circuit is considered, reactance voltage drops are equal to the per unit reactances expressed as fractions of rated voltage. The air gap ampere turns corresponding to rated voltage and speed are defined as unit ampere turns.

Table I—Results of Calculations for Maximum Flux Density

No.	Poles	Kva	B_{sc}	B_{sc}/X_d
1	4	390	0.45	0.372
2	6	175	0.345	0.268
3	8	2,500	0.355	0.261
4	8	20,000	0.395	0.315
5	8	20,000	0.31	0.273
6	10	20,000	0.59	0.40
7	18	1,750	0.332	0.261
8	20	1,000	0.315	0.255

On this basis, the nominal voltage on short circuit is equal to the synchronous reactance, X_d. The field excitation in terms of unit ampere turns is also equal to the synchronous reactance. The demagnetizing ampere turns of the armature are equal to the magnetizing reactance, X_{ad}. The maximum value of the magnetomotive force of the armature is $X_{ad} \div C_m$, where C_m is the ratio of the fundamental of the direct axis field form obtained when the armature only is excited to the fundamental of the field form obtained when the field only is excited. The resultant magnetomotive force across the air gap, therefore, increases sinusoidally from a minimum of $X_d - (X_{ad} \div C_m)$ at the pole center line to a maximum of X_d at the center line between poles. This is represented by curve 2 on figure 1. This resultant magnetomotive force acting on the air gap reluctance produces the short circuit field form represented by curve 3 of figure 1, which is calculated from the flux plot shown.

The pole face contour, which determines the air gap reluctance at any point, varies in different machines and cannot readily be represented mathematically. In order to obtain a simple method of calculating the maximum gap density on short circuit B_{sc} a number of flux plots similar to that of figure 1 were made. The results are given in table I. These results indicate that with the exception of the first and sixth examples, $B_{sc} = 0.27\ X_d$ approximately. The exceptions are machines whose pole contours were concentric with the air gap and not "smoothed off" at the tips as is customary. In such cases B_{sc} should be obtained by plotting the field form for short circuit conditions.

Armature Tooth Loss

Since the loss at 60 cycles in silicon core punchings is mostly hysteresis loss, the load loss in the teeth will depend mainly upon B_{sc} and the shape of the hysteresis loop. The hysteresis cycle contains 2 large displaced loops whose total area is about equal

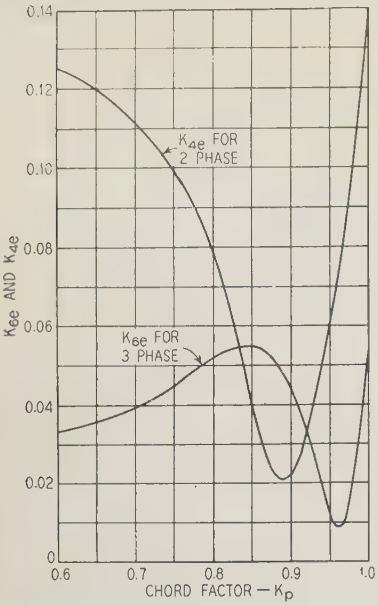


Fig. 2. Effect of coil pitch upon the phase belt harmonic losses as given by equations 15 and 19

to that of the normal loop. The maximum tooth density on short circuit is B_{sc} × (tooth density at no load rated voltage). The load loss in the teeth can be calculated from the same curves used to get the no load tooth loss, except the result must be multiplied by 2 to correct for the displaced hysteresis loops.

End Finger Loss

The loss in the supporting fingers at the ends of the core is almost entirely a loss of the eddy current type. This loss arises from the fringing flux entering the fingers from the ends of the pole. The no load finger loss is calculated in terms of the maximum density in the gap at no load, B_g. Since the finger loss is an eddy loss, it can be calculated for short circuit conditions as the sum of the losses produced by each individual harmonic of the short circuit field form. Assuming that the loss for each harmonic varies as the square of its frequency and maximum density, it may be calculated as follows. The maximum value of the fundamental is equal to the armature leakage reactance X_L, and the loss is X_L^2 × (no load finger loss). Since X_L seldom exceeds 20 per cent, the loss due to the fundamental may be neglected.

The maximum value of the third harmonic is roughly 0.6 B_{sc} for average proportions. The loss due to the third harmonic then is $9\,(0.6\,B_{sc})^2 = 3.24\,B_{sc}^2$ × (no load finger loss). Similarly, the fifth harmonic contributes 1.5 B_{sc}^2. The effect of higher harmonics decreases rapidly with the order of the harmonic. For a machine of average proportions, the sum of the losses of all harmonics is:

$$\text{End finger loss} = 5(B_{sc})^2 \times (\text{no load finger loss}) \tag{1}$$

Phase Belt Harmonic Losses

The magnetomotive force produced by current in one phase of the armature winding is trapezoidal in shape. The width of the base of the trapezoid is the pole pitch T_r. The width of the top is $T_r - 2L$, where $2L$ = width of one phase belt. Representing the trapezoidal wave by a Fourier series, the maximum value of the nth harmonic is,

$$\frac{4}{n\pi}\,\frac{\sin nL}{nL}$$

The ratio of the maximum value of the nth harmonic to that of the fundamental is,

$$\frac{K_{pn}\sin nL}{K_p n^2 \sin L} \tag{2}$$

where K_{pn} and K_p are the chord factors for the nth harmonic and fundamental, respectively. This ratio is also true for the total magnetomotive force of all phases acting together. Since the maximum value of the fundamental of armature magnetomotive force is $X_{ad}\,AT_g \div C_m$ ampere turns, the maximum value of the nth harmonic is

$$A_n = \frac{X_{ad}AT_gK_{pn}\sin nL}{C_m n^2 K_p \sin L}\ \text{ampere turns} \tag{3}$$

See appendix I for a list of symbols.

In a 3 phase machine the fifth harmonic rotating in the opposite direction from that of the fundamental at one fifth of synchronous speed cuts the field surface at 6 times fundamental frequency. The seventh harmonic rotating in the same direction as the fundamental at one seventh of synchronous speed also cuts the field surface at 6 times rated frequency. These 2 harmonics combine to produce a flux of 6 times fundamental frequency entering the field surface and causing pole face loss. If a damper winding is present, this flux is damped out by currents of 6 times fundamental frequency in the damper winding, resulting in damper loss.

The eleventh and thirteenth harmonics likewise combine to produce flux of 12 times rated frequency in the field, and Doherty and Nickle[2] have shown that all multiples of the sixth harmonic may exist in the field. The magnitudes of these harmonics of higher order are sufficiently small that they may be neglected from the standpoint of loss, even though their frequencies are high.

In a 2 phase machine, the third and fifth harmonics of armature magnetomotive force combine to produce a fourth harmonic of flux in the field. The resulting losses are usually much larger than the sixth harmonic losses in a 3 phase machine. This accounts for the observed tendency of 2 phase machines to have higher load losses than comparable 3 phase machines. The losses caused by multiples of the fourth harmonic may be neglected.

Phase belt harmonic losses in the damper winding result from current flowing through resistance. Since the pole laminations are of relatively high resistivity and thickness, the pole face loss is principally eddy current loss. It is, therefore, necessary to examine the way in which the 2 harmonics combine at various points along the pole surface and obtain an effective value of the resultant magnetomotive force averaged over the pole face. The fifth and seventh harmonics are in time phase at the pole

center line and rotate negatively with respect to the pole surface. They are 180 degrees out of phase at the center line between poles. At any intermediate point at an angle θ from the pole center line, the phase angle between A_5 and A_7 is 2θ. The resultant magnetomotive force at any point is the vector sum of A_5 and A_7. The effective value of the resultant averaged over the pole face for an average pole width of $^2/_3$ the pole pitch is:

$$A_{6e} = \sqrt{\frac{3}{\pi}\int_0^{\pi/3} (\dot{A}_5 + \dot{A}_7)d\,\theta}$$

$$= \sqrt{\frac{3}{\pi}\int_0^{\pi/3} [A_5^2 + A_7^2 + 2A_5A_7 \cos 2\theta]d\,\theta} \tag{4}$$

$$A_{6e} = 0.98\sqrt{A_5^2 + A_7^2 + 0.866\,A_5A_7}$$

The corresponding value of A_{4e} for a 2 phase machine is:

$$A_{4e} = 0.98\sqrt{A_3^2 + A_5^2 + 0.866\,A_3A_5} \tag{5}$$

The numerical values of K_{6e} and K_{4e}, where

$$A_{6e} = \frac{K_{6e}X_{ad}AT_g}{C_m} \qquad A_{4e} = \frac{K_{4e}X_{ad}AT_g}{C_m} \tag{6}$$

are plotted as functions of the fundamental chord factor in figure 2.

Phase Belt Harmonic Loss in the Damper Winding

Taking the maximum value of the nth harmonic of magnetomotive force as unit ampere turns, the nth harmonic flux linked by a pair of damper bars is:

$$\phi_p = \frac{3.19 \times 0.636\,T_r \sin(\delta_n/2)}{n\,g_e} \tag{7}$$

where

$$\delta_n = \frac{N\,T_b \times 180 \text{ degrees}}{T_r} \tag{8}$$

The mutual flux which links the pair of bars in addition to ϕ_p, due to currents in the 2 damping circuits on each side of the one considered is:

$$\phi_m = 3.19\sqrt{2}\,I_c \times 2\,\lambda_s \cos\delta_n \tag{9}$$

where I_c is the current in each damping circuit.

$$I_c = \frac{\phi_p + \phi_m}{3.19\sqrt{2}\,(\lambda_g + 2\lambda_s)} \tag{10}$$

The resultant current in a damper bar is:

$$I_{rn} = I_c\sqrt{2(1 - \cos\delta_n)} \tag{11}$$

Substituting equations 7 and 9 in 10, solving for I_c, substituting the resulting value of I_c in equation 11, and rearranging gives:

$$I_{rn} = \frac{0.636\,T_r}{\sqrt{2}\,n\,g_e\left[\dfrac{\lambda_g}{1 - \cos\delta_n} + 2\,\lambda_s\right]} \tag{12}$$

The derivation of equation 12 is made very brief here, since the solution is given in detail in reference 3 at the end of the paper, equations 1 to 6.

The total sixth harmonic current at the pole center line of a 3 phase machine is:

$$I_6 = \frac{0.636\,T_r}{\sqrt{2}\,g_e}\left\{\frac{A_5}{5\left[\dfrac{\lambda_g}{1 - \cos\delta_5} + 2\,\lambda_s\right]} + \frac{A_7}{7\left[\dfrac{\lambda_g}{1 - \cos\delta_7} + 2\,\lambda_s\right]}\right\} \tag{13}$$

This equation may be simplified without great loss of accuracy by assuming that 5 and 7 in the denominators of the bracketed quantity equal 6 and that $\delta_5 = \delta_7 = 6\,T_b \times 180$ degrees$/T_r$. Making these approximations and substituting the effective value of the resultant of A_5 and A_7 given by equation 6 gives:

$$I_6 = \frac{0.636\,T_r}{6\sqrt{2}\,g_e}\left[\frac{K_{6e}\,X_{ad}\,AT_g}{C_m\left(\dfrac{\lambda_g}{1 - \cos\delta_6} + 2\,\lambda_s\right)}\right] \tag{14}$$

The effective damper bar resistance is $\rho l\;K_f \div 10^6\,a$. The constant C_m does not vary widely in different machines and is equal to 0.84, approximately. Then the total sixth harmonic loss in the damper winding is I_{6e}^2 multiplied by the effective bar resistance and the total number of bars N:

$$W_{D6} = \frac{0.792\rho l\,K_fN}{10^{11}a}\left\{\frac{T_r}{g_e}\right\}^2\left[\frac{K_{6e}X_{ad}AT_g}{\dfrac{\lambda_g}{1 - \cos\delta_6} + 2\,\lambda_s}\right]^2 \tag{15}$$

Equation 15 gives the loss in kilowatts.

The loss in a 2 phase machine W_{D4} is obtained by substituting 1.78 for the constant 0.792 and δ_4 for δ_6 in equation 15. $\delta_4 = 4\,T_b \times 180$ degrees$/T_r$. Also, the increase in bar resistance K_f must be calculated at 4 times instead of at 6 times rated frequency.

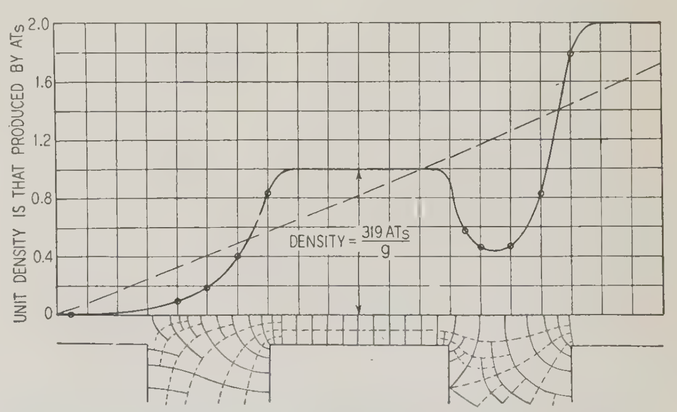


Fig. 3. Distribution of flux density at pole surface due to equal currents in 2 adjacent stator slots

Return currents are in slots to the right of these
$b_s/g = 4 \quad b_s/T_s = 0.4$

Phase Belt Harmonic Loss in the Pole Face

When a damper winding is present in the pole face, induced currents in the bars damp out most of the

harmonic flux which would otherwise enter the pole face. Consequently loss in the pole face is negligible. However, if the machine is not equipped with a damper winding, the pole face loss may become important, particularly in 2 phase machines.

Assume temporarily that the harmonic pole span is equal to the armature slot pitch T_s and that the harmonic cuts the pole surface at armature slot frequency. Then the total effective harmonic flux in a half cycle of the harmonic is:

$$\frac{3.19\, X_{ad}\, AT_g}{C_m\, g} K_e \times 0.636\, T_s$$

The total flux in a half cycle of the ripple producing the no load pole face loss is:

$$159\, T_s\, B_g\, K_{w1}\, K_s\, K_g \cdots {}^3$$

Assuming the pole face loss to vary as the square of the flux density, the harmonic loss in the pole face is:

$$W_p = \left\{\frac{3.19\, X_{ad}\, AT_g\, K_e\, T_s \times 0.636}{159\, T_s\, B_g\, K_{w1}\, K_s\, K_g\, g_e\, C_m}\right\}^2 \times \text{(no load pole face loss)}$$

Since $AT_g = 314\, B_g g_e$ and since $C_m = 0.84$ approximately,

$$W_p = \left\{\frac{4.77\, X_{ad}\, K_e}{K_{s1}\, K_s\, K_g}\right\}^2 \times \text{(no load pole face loss)} \qquad (16)$$

Spooner[4] has shown that the pole face loss varies as the 1.6 power of frequency and as the 1.3 power of the wave length of the pulsation. The harmonic frequency is nf and the armature slot frequency is $2f \times$ (number of slots per pole) so that the error resulting from assuming the harmonic frequency to be equal to armature slot frequency can be corrected by multiplying equation 16 by the factor $\left\{\frac{nf}{2f \times \text{(slots per pole)}}\right\}^{1.6}$ Correction for pole span or wave length can be made by multiplying by $(T_r/n\, T_s)^{1.3}$. Applying these corrections, equation 16 becomes:

$$W_p = \left\{\frac{4.77 X_{ad} K_e}{K_{w1}\, K_s\, K_g}\right\}^2 \left\{\frac{nf}{2f\text{ (slots per pole)}}\right\}^{1.6} \left\{\frac{T_r}{nT_s}\right\}^{1.3} \qquad (17)$$

Since T_r/T_s = slots per pole and approximate values for K_{w1} and K_g are 0.97 and 1.1, respectively:

$$W_p = 6.57 \left\{\frac{X_{ad}\, K_e}{K_s}\right\}^2 \left\{\frac{n}{\text{slots per pole}}\right\}^{0.3} \times \text{(no load pole face loss)} \qquad (18)$$

Equation 18 is in a practical form for routine calculations, but may be further simplified by assuming an average number of slots per pole equal to 12. Then, since $n = 6$, the loss in a 3 phase machine is:

$$W_p = 5.35 \left\{\frac{X_{ad} K_{6e}}{K_s}\right\}^2 \times \text{(no load pole face loss)} \qquad (19)$$

For 2 phase, $n = 4$ and the constant becomes 4.7 instead of 5.35.

Slot Harmonic Losses

At no load the nonuniform air gap permeance resulting from the stator slots superimposes a slot harmonic or ripple on the no load field form. Since the field poles are rotating with respect to the stator slots, this harmonic moves relative to the pole face from one tip to the other, resulting in losses in the pole face and in the damper winding. Methods given in references[3,4] are available for calculating these no load losses.

Under short circuit conditions a similar phenomenon exists and the short circuit losses can be calculated in terms of the no load losses. Distribution of the armature current among several slots in each pole results in a magnetomotive force wave with a saw tooth shape. The resulting flux wave also has a saw tooth shape, which is magnified by the nonuniform air gap permeance due to the open armature slots. A portion of such a flux wave, together with the flux map from which it was calculated, is shown in figure 3. The effect of the field magnetomotive force is neglected. Comparison with figure 1 shows that the left side of figure 3 corresponds to the point near the pole center line at which the resultant magnetomotive force becomes positive. Since the currents in both slots of figure 3 were assumed equal, the average flux density across the air gap increases linearly from left to right and the flux pulsation which produces the loss is represented by the difference between the actual density and the straight line average.

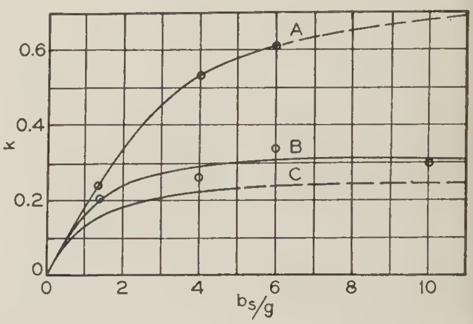


Fig. 4. Effect of slot/gap ratio on the constant k in the equation: $\phi_{sc} = \sqrt{2} k AT_s T_s/g$

A—Current in slot equals currents to left of slot considered, as in the right-hand slot in figure 3

B—No currents to left of slot; all ampere turn lines from the slot terminate to the right, as with the left-hand slot in figure 3

C—No currents to left of slot; ampere turn lines divide half to right and half to left of slot

For a uniform air gap and point concentration of armature current, the total flux across the gap for one slot pitch is:

$$\frac{3.19\sqrt{2}\, T_s\, AT_s}{g}$$

Defining k as the ratio of the total flux in $1/2$ cycle of pulsation to the flux represented by the area $T_s\, AT_s$, then the pulsation flux per half cycle is:

$$\phi_{ps} = \frac{\sqrt{2}\, k\, T_s\, AT_s}{g}$$

The curves of k as a function of slot to gap ratio, shown in figure 4, were obtained from several flux maps similar to figure 3 for various ratios of slot to gap. As indicated by figure 3, the value of k for a

given slot to gap ratio varies depending upon the proportion of ampere turn lines which terminate in slots to the left of the slot for which k is calculated. Three k curves are plotted in figure 4: for equal ampere turn lines terminating in the slot and to the left of the slot, for no ampere turn lines terminating to the left of the slot (corresponding to the left hand slot in figure 3), and for the condition when half of the ampere turn lines from a slot terminate on each side of the slot. The last condition corresponds to a slot whose center line is at the point at which the resultant magnetomotive force becomes positive, near the pole center line on figure 1.

The armature current per slot AT_s is distributed sinusoidally on short circuit and is zero at the pole center line, and maximum at the center line between poles. At any point along the pole surface the proportion of ampere turn lines terminating to the left of the point is represented by curve 2 of figure 1, from which the value of k at that point may be determined. The value of the product of k and current per slot at each point along the pole surface is plotted in figure 5 for a slot to gap ratio of 4. The effective value of this curve is 0.20. Then the effective value of pulsation flux per half cycle, averaged over the whole pole surface is:

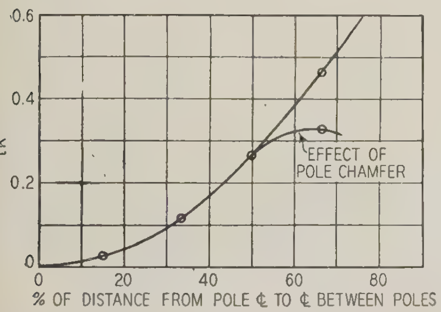


Fig. 5. Value of the product of k and current per slot at each point along the pole face, plotted for a slot to gap ratio of 4

$$\text{Effective value of } ik = 0.20\ K_{sc} = \frac{0.20\sqrt{2} \times 314}{0.097 \times 159 \times 0.55} = 1.05$$

$$\phi_{ps} = \frac{\sqrt{2}\ k_{eff.} T_s\ AT_s}{g} \qquad (20)$$

in which $k_{eff.}$ is 0.20 for $b_s/g = 4$.

The magnitude of the flux per half cycle of the flux ripple producing the no load pole face and damper loss is:

$159\ T_s\ B_g\ K_{w1}\ K_s\ K_g \cdots$ [3]

Assuming that the loss varies as the square of the ratio of flux per half cycle of pulsation, the pole face and damper losses on short circuit are:

$$W_s = \left[\frac{\sqrt{2}\ k_{eff.}\ T_s\ AT_s}{159\ g\ T_s\ B_g\ K_{w1}\ K_s\ K_g}\right]^2 \times \text{(no load pole face plus damper loss)}$$

Since $AT_g = 314\ B_g\ K_g\ g$,

$$W_s = \left[\frac{314\sqrt{2}}{159}\ \frac{k_{eff.}}{K_{w1}K_s}\ \frac{AT_s}{AT_g}\right]^2 \times \text{(no load pole face plus damper loss)} \qquad (21)$$

For a ratio of slot width to slot pitch of 0.4, which is a good average value of this ratio, $K_{w1} = 0.97$. Defining

$$K_{sc} = \frac{314\sqrt{2}\ k_{eff.}}{159\ K_{w1}\ K_s} = \frac{2.89\ k_{eff.}}{K_s},$$

$$W_s = \left[\frac{K_{sc}\ AT_s}{AT_g}\right]^2 \times \text{(no load pole face and damper loss)} \qquad (22)$$

Since both $k_{eff.}$ and K_s are functions of the slot to gap ratio, the quantity K_{sc} may be plotted against slot to gap ratio as in figure 6.

End Zone Losses

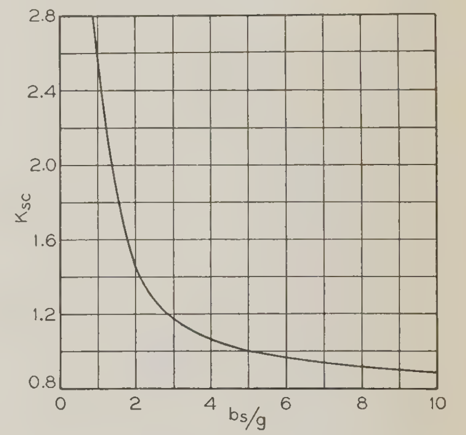
Leakage fields set up by currents in the end portions of the armature coils produce losses in the end bells, end plates, and coil supporting rings. The loss in the rings is an insignificant part of the total load loss and may be neglected from the standpoint of loss only, although it may result in serious local heating. A method of calculating the end bell and end plate losses has been developed by L. A. Kilgore,[5] which is presented in curve form in figure 7.

Losses at Rated Load Voltage, and Power Factor

The previous discussion has been confined to losses occurring during operation on short circuit, which are used in calculating the conventional efficiency. Engine and turbine builders must frequently guarantee over-all fuel consumption rates

Fig. 6. Short circuit pole face and damper winding loss

These losses, together, equal $\left(\frac{K_{sc}AT_s}{AT_g}\right) \times$ (no load pole face plus damper loss)



when the generator is operating at rated conditions. Consequently this class of purchaser is more concerned with the losses existing while the generator is operating not only with rated current but at rated voltage and power factor as well. The eddy loss in the armature copper and the end bell and end plate losses are practically the same as on short circuit.

At zero power factor the phase belt losses are the same as for short circuit conditions. At higher power factors these losses may be reduced by as much as 8 per cent below the values obtained on short circuit. This is caused by the angular shift of the pole center line from the peak of the armature magnetomotive force wave ($\alpha + \theta$) which changes the limits of inte-

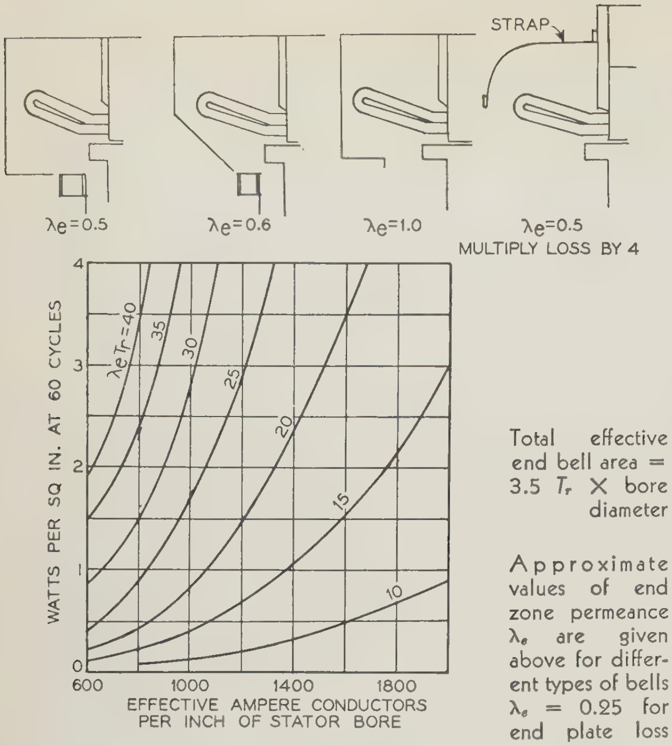


Fig. 7. Load loss in end bells and end plates

gration of the integral preceding equation 4 and reduces the constant 0.866 in equation 4 to as low as 0.43.

The load losses in the stator teeth and fingers are much higher than for short circuit conditions, since the field form in the air gap under load is highly distorted.

A field form for a typical machine at rated load and voltage, at 0.8 power factor, is shown in figure 8. Curve *a* is the resultant of field magnetomotive force and direct axis armature magnetomotive force, having a magnitude of $e_d - X_{ad}/C_m \sin(\alpha + \phi)$ at the pole center line and of e_d at the center line between poles. Curve *a* multiplied by the no load wave form gives the direct axis full load field form represented by curve *b*. Curve *a* is the field form produced by the quadrature axis component of armature current multiplied by $X_{ad}/C_m \cos(\alpha + \phi)$. The resultant distribution of flux in the air gap is given by curve *d* which is the sum of curves *b* and *c*. The effect of saturation of the stator teeth is neglected in curve *d*, which becomes curve *e* when corrected for saturation.

The load loss in the stator teeth is calculated in the same manner as for the no load tooth loss, except that a tooth density corresponding to the maximum value of curve *e*, of figure 8, is used and the effects of displaced hysteresis loops must be corrected for, if present. The no load tooth loss is subtracted from this since it is already included as a component of the no load core loss. The load losses in the fingers may be calculated in a similar manner.

The slot harmonic losses in the pole face and damper winding presents a more difficult problem. A rough approximation is to calculate these losses in the same manner as for no load, except based upon the effective density at full load averaged along the pole face, subtract the no load loss calculated at no load density, and add the pole face and damper loss for short circuit conditions.

Summary—Short Circuit Loss Calculations

In most cases the largest single component of the load loss is that of eddy loss in the armature conductors. The eddy loss may be minimized by multiple stranding of the conductors and by avoiding the use of less than 4 turns per coil. Where the latter is unavoidable, external or even internal transpositions may be justified.

Since the eddy loss is relatively large, it must be calculated accurately. It is particularly important to estimate carefully the temperature of the armature windings during the short circuit test, as the temperature is a controlling factor. It is also important to measure the temperature of the armature winding at the time the test is made or errors as large as 100 per cent may occur in the test results, if the load loss is small compared to the armature copper loss.

The armature tooth loss seldom exceeds 20 per cent of the total load loss. It may be kept to a minimum by shaping the pole face in such a manner as to round off the sides of the no load field form and by the use of silicon steel armature laminations.

The end finger loss is usually small. However, in the eighth example of table II this loss is 45 per cent of the total load loss, due to the use of magnetic end fingers in combination with large cast pole end plates extending axially beyond the core. This loss can be minimized by shaping the pole face, by the use of nonmagnetic fingers, and by preventing axial extension of magnetic parts of the pole head beyond the ends of the armature core.

The phase belt harmonic losses are generally low enough to be of secondary importance on 3 phase machines with low resistance dampers or without dampers. Even with high resistance dampers this loss is small, if a coil throw of 80 per cent is used. The phase belt loss may be quite large in 2 phase machines with full pitch coils, as in example 16 of table II. Figure 2 shows that the phase belt losses vary greatly depending upon the coil throw, and that a chord factor of 0.866 should be used for 2 phase machines when possible. An example of this is number 5 of table II, in which the phase belt losses are quite low for a 2 phase machine.

The slot harmonic losses are usually important in engine type machines which inherently have high no load pole face and damper losses and in machines with high resistance damper windings. Numbers 17 and 25 of table II are good examples of these 2 classes of machines, respectively. The slot harmonic losses may be kept low by designing for low no load pole face and damper losses, particularly by the use of many armature slots with low ampere turns per slot.

The magnitude of the end bell and end plate losses varies considerably with the type of construction and is seldom a very large proportion of the total load loss. It is negligible in engine type machines and is small in vertical machines. It is greatest for those

Table II—Short Circuit Load Loss Calculations (All Losses Are in Kilowatts)

No.	Kva	Poles	Eddy Loss	Tooth Loss	Finger Loss	W_P	W_S	W_R	W_B	Total Calc. Loss	Test Loss
1	500	4	0.34	0.18	0.06	0.14	0.15	0.04	1.8	2.71	2.9
2	1,500	6	4.96	0.93	0.13	2.3	1.35	0	1.7	11.37	11.4
3	288	8	0.20	0.11	0.05	0.10	0.165	0	0.04	0.67	0.60
4	10,000	8	28.9	12.8	3.5	1.07	6.3	0	2.4	76.7	71.9
5	20,000	10	33	7.3	0.91	1.9	7.0	0	4.5	54.6	54
6	30,000	10	31	9.8	1.8	1.2	13.4	1.2	7.8	66.2	71
7	1,500	12	2.8	1.0	4.5	0.42	0.62	0	1.1	10.4	9.85
8	30,000	12	43.8	10.9	2.3	8.6	9.1	0	12.3	87	76
9	875	14	0.81	0.38	0.08	0.16	0.87	0	0	2.3	2.2
10	30,000	14	59.2	12.6	2.8	8.4	14.6	0	6.1	103.7	99
11	250	32	0.30	0.38	0.03	0	0.55	0	0	1.26	1.0
12	781	54	2.29	0.75	0.17	0.57	0.93	0	0	4.71	4.86
13	2,000	58	6.85	2.37	0.31	0.38	4.7	0	0	14.6	15.9
14	23,000	64	15.8	9.7	1.0	2.4	9.3	4.0	0.6	42.8	43
15	31,000	66	90.2	1.5	1.3	0.7	26	0	0.8	133.5	90.5
16	5,000	88	10.1	1.4	0.68	2.9	7.1	0	0	22.2	22.5

horizontal machines combining the unfavorable features of large pole pitch, relatively short core length, with enclosing end bells brought in close beneath the armature end winding, and without shrouded blowers. Example 1 of table II is an exceptional case in which all of these factors contributed to the high end bell loss. To avoid high loss, the bells should be kept as far away from the coils as possible at all points and a shrouded blower is desirable, since it diverts part of the flux which otherwise would enter the end bell.

The comparison between calculated and test values of short circuit load loss given in the last 2 columns of table II provides a check for the accuracy of the formulas. The load losses as determined by tests of 2 duplicate machines built to the same specifications may vary by as much as 20 per cent, in exceptional cases. The causes of this are variations in materials and in manufacturing. The results set forth in table II may, therefore, be considered acceptable.

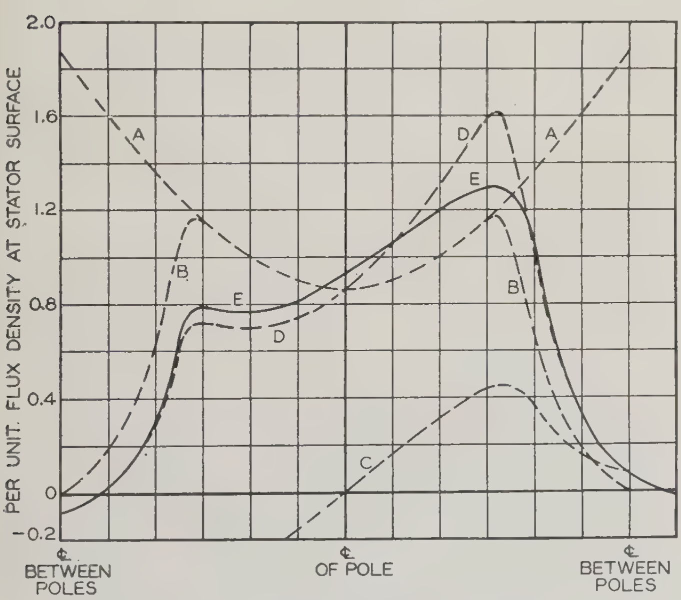


Fig. 8. Flux density at stator surface

A—Resultant of field magnetomotive force and direct axis armature magnetomotive force

B—Flux wave due to *A*

C—Flux wave due to quadrature axis component of armature current

D—Flux wave at full load, rated voltage, 0.8 power factor, neglecting stator tooth saturation. Resultant of *B* and *C*

E—Curve *D* corrected for tooth saturation

Unit density is density at center line of pole at no load and rated voltage

Summary—Calculations of Load Loss Under Rated Conditions

Although load losses at rated load and voltage and at 0.8 power factor have been calculated for a few of the machines listed in table II, the results are not given since corresponding test data are not available. Floyd and Dunbar[6] tested a 55,000-kva 16-pole 25-cycle generator under both short circuit and rated conditions and obtained losses of 104 and 135 kw, respectively. Using the methods suggested herein, the calculated short circuit load loss is 122 kw and the calculated load loss under rated conditions is 148 kw.

The load loss at rated voltage and current is minimum at zero power factor and maximum near unity power factor, since the field form distortion due to the quadrature axis component of current is absent at zero power factor and is maximum near unity power factor.

Delta Connection or Star Connection With Grounded Neutral

If the armature winding is connected in delta or in star with a grounded neutral, the third harmonic series of zero phase sequence currents circulate through the winding unless it is chorded to $^2/_3$ pitch. The additional losses in the armature and damper windings may increase the short circuit loss by as much as 50 per cent.

Appendix I—List of Symbols

a = area of damper bar in square inches

A_n = maximum value of nth harmonic of armature magnetomotive force in ampere turns

A_{se} = effective value taken over pole surface of the vector sum of maximum values of third and fifth harmonics of armature magnetomotive force in ampere turns

A_{6e} = same as A_4e, except is sum of fifth and seventh harmonics
AT_s = armature ampere turns per slot
AT_g = air gap ampere turns at no load
b_s = armature slot width
B_g = maximum density in air gap at no load in kilolines per square inch
B_{sc} = maximum density in air gap under short circuit conditions expressed as a fraction of Bg
C_m = ratio of fundamental of direct axis field form with armature alone excited to fundamental of no load field form
f = fundamental frequency of the machine in cycles per second
g = air gap length in inches
g_e = effective air gap length = gK_g
I_c = current in the closed circuit consisting of 2 adjacent damper bars
I_{rn} = resultant nth harmonic current in damper bar
I_{6e} = effective value of sixth harmonic current in damper bar
k = ratio of total flux in a half cycle of the slot harmonic to the flux represented by the area $T_s\ AT_s$ of figure 3, multiplied by 3.19
K_{4e}, K_{6e} = defined by equation 6
K_g = Carter's air gap coefficient
K_f = ratio of a-c to d-c resistances for damper bar
K_p = chord factor for the fundamental
K_{pn} = chord factor for the nth harmonic
K_s = ratio of double amplitude of slot ripple to B_g:

$$K_s = 1 - \frac{1}{\sqrt{1 - (b_s/g)^2}}$$

K_{sc} = $2.89k_{eff.}/Ks$
K_{w1} = ratio of fundamental of slot ripple to $^1/_2$ of K_s
L = width of one phase belt
l = core length
n = order of harmonic
T_b = damper bar pitch in inches
T_r = pole pitch in inches
T_s = slot pitch in inches
W_B = end bell loss
W_{D4} = phase belt harmonic loss in damper winding for 2 phase machines
W_{D6} = phase belt harmonic loss in damper winding for 3 phase machines
W_P = phase belt harmonic loss in pole face
W_R = loss in armature coil supporting rings
W_S = slot harmonic loss in pole face and damper winding
X_d = $X_l + X_{ad}$ = synchronous reactance in "per unit"
X_{ad} = magnetizing reactance in per unit
X_L = armature leakage reactance in per unit
δ_n = defined by equation 8
α = power displacement angle of rotor
ϕ_p = air gap harmonic flux linked by a pair of adjacent damper bars in lines per inch of length
ϕ_m = mutual flux linked by a pair of adjacent damper bars in lines per inch of length
ϕ_{ps} = slot harmonic flux per half cycle in lines, per inch of length
λ_g = air gap permeance for circuit consisting of 2 adjacent damper bars
λ_s = damper slot permeance
λ_e = permeance of flux path from end of core to end bell
ρ = resistivity in microhms per cubic inch
θ = angle measured from pole center line

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The "Biway" System of

Electric Platforms for Mass Transit

This paper describes the "biway" system of mass transit by continuously moving electrically operated platforms which is cited as being suitable for use in the congested sections of large cities. It is planned to have 2 adjacent moving platforms, one of which operates continuously at a speed of about 15 miles per hour, the other of which varies between standstill and the speed of the continuously moving platform to enable passengers to transfer between the stationary and moving platforms. The biway offers convenience in that it may be boarded at any point on the system and will give a nonstop ride to within a short distance of the destination, greater speed than existing transit methods for short distances, seating capacity up to 60,000 passengers per hour past a given point, and economy of operation by the use of regeneration. Figures given in the paper show that the biway may be less expensive than subways and give better service.

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THE PROBLEM of providing adequate means of transit in the congested business districts of large cities has not yet been solved, and is daily becoming more difficult and important. Every new building that is taller than the one it replaces makes the problem more difficult of solution. If the cities of the future are to be made up of skyscrapers, it is impossible to escape the conclusion that there will have to be more and wider streets or the present streets will have to be double or triple decked unless a radical change in the present methods of short haul transit is made. Certainly the present methods are neither adequate nor satisfactory.

Under normal conditions, a street car, bus, or

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taxicab can make an average speed of from 5 to 7 miles per hour through the business section of a large city, but the addition of a few more people or vehicles on the street, or a light shower, nearly blocks the traffic. At no time are the elevated or subway trains satisfactory for short hauls, because of the distance between stations and the time intervals between trains.

The prime requisite for an adequate means of rapid transit in a large city is a private right of way. This is, of course, impossible at street levels as cities are now constructed. Such semiprivate routes as Riverside Drive in New York City are a great boon for de luxe travel, but are practically useless for mass transit. The private right of way for mass transit must be easily accessible from the streets or buildings. It must have capacity to handle the crowds that are present during the rush hours, and do it without crowding. Its speed should be affected neither by the number of passengers nor the weather.

A great many solutions for this problem have been proposed, other than subways and more subways, of which the favorite has been some form of nonstop or continuous transit scheme. The advantage of a nonstop run has been recognized for a long time. It was evidently well understood when Ebenezer Hawkins of Islip, N. Y., took out a patent on December 9, 1874, covering a means for giving intermediate towns the advantage of a high speed nonstop train running through them. He proposed to provide for these towns by means of a light train which would accelerate from a local station on a track adjacent to the one on which the nonstop train was approaching, run beside this train for a short distance at the same speed and, with the 2 trains hooked together, interchange passengers and baggage, unhook, and stop at the next station. Of course, it was a fantastic idea, and probably never was tried, but it contained the germ of a scheme for continuous mass transit.

Continuous Transit by Moving Sidewalks

Many years ago, some one proposed the idea of a continuously moving sidewalk on which pedestrians could ride, and by walking at the same time, could increase their rate of travel. Many serious attempts have been made to utilize this idea for mass transit. The first moving platform used for carrying passengers was installed at the World's Fair in Chicago in 1893. It had 2 continuous belts of platform running side by side at constant speeds, one at 3 miles per hour, the other at 6 miles per hour. The latter was provided with seats. Passengers stepped from a stationary platform to the slow speed, and from that to the high speed one. This platform was about 4,500 feet long, built on a pier running out into Lake Michigan. It was well patronized during the Fair.

The next time moving platforms for carrying passengers were used was in 1896 at an industrial exposition in Berlin where it was used to connect the exposition grounds with a nearby amusement park. It was similar in operation to the one at Chicago and was also quite successful. Again at the Paris Exposition in 1900 the moving platform appeared, this time as a component part of the transportation system. It was 10,900 feet long, and, located on a viaduct, 23 feet above the ground, served admirably to give the passengers a bird's-eye view of the exposition, as well as to transport them. This installation also had 2 platforms running respectively at 3 and 6 miles per hour. It operated successfully throughout the exposition, and carried over 7,000,000 passengers.

Continuous-Motion Variable-Speed System

A scheme very different from moving platforms was proposed by B. R. Adkins and W. Y. Lewis (*Scientific American*, April 6, 1907). This scheme provided for a number of separate 4-wheeled cars which would be bunched close together at stations, where there would be a continuous stream of these cars moving at a speed of 3 miles per hour. As soon as each car passed the station, it would be accelerated to about 21 miles per hour, which would separate the cars, leaving about 6 car lengths between adjacent cars, until the next station was reached, when the speed would be again reduced to 3 miles per hour. The article stated: "The method of driving the cars at this variable rate is very simple. On each side of the track, extending along the entire length of the line, is a pair of screws or rather shafts, in each of which a spiral groove is cut. One of these is formed with a right-hand spiral, and the other with a left-hand spiral. These opposed spiral grooves receive the opposite ends of the forward axle of each car so that when the shafts are turned in opposite directions, they feed or 'screw' the cars forward. The desired acceleration or retardation of the cars is produced by varying the pitch of the grooves."

Fig. 1. Depiction of the biway in operation

One can visualize many difficulties with the screws, particularly since it would be practically impossible to have such a drive on curves and the cars would consequently have to coast through them. The capacity of the system would be comparatively small and the average speed would be low, but the

scheme had the advantage of continuous loading and unloading at every station on the line, but always to or from a train moving at a speed of 3 miles per hour.

Putnam's Moving Platforms

Between 1920 and 1925, Henry S. Putnam of New York developed a system involving the use of 3 continuous constant-speed platforms running at 3, 6, and 9 miles per hour, respectively. Aside from a novel scheme for driving them and the use of 3 platforms to get a higher speed, the scheme of operation was practically the same as that of his predecessors. A demonstration plant was built at Jersey City, N. J., in the form of a loop 200 feet long and 100 feet wide, with a radius of 50 feet at each end. The 3 and 6 mile per hour platforms were 27 inches wide, and the 9 mile per hour platform was 57 inches wide with double seats spaced 32 inches apart. This gave a real working model.

Putnam had 2 methods for operating the demonstration platforms. The 9 mile per hour platform was driven by the inductive method, using a kind of glorified induction motor with an infinite radius of rotor. The primary of the motor was divided into short sections distributed along the middle of the track, while the secondary was carried under the platform and extended its entire length. It gave a constant speed with no gears or other rotating parts, but was very inefficient. The 3 and 6 mile per hour platforms were driven by rack and pinion, with the rack under the platform extending the entire length, and driven by pinions on countershafts driven, in turn, by motors through chains and sprockets.

The demonstration plant was thoroughly tested and inspected by many people. Largely as a result of this, a report of the Transit Commission of the State of New York was made on an installation for 42d Street, New York, from the Hudson River to the East River. This report went into the subject in great detail and covered everything concerned. It was, on the whole, very favorable to the moving platform scheme, but the project never went through.

There are 2 objections to this system that undoubtedly helped to prevent its adoption:

1. The necessity for passengers to step from one moving platform to another moving at a speed of 3 miles above or below its own speed. There undoubtedly would be many people unable or unwilling to do this, which would be a great handicap to the system. It would be equivalent to a moving stairway running at 3 times its usual speed.

2. The limited speed, for while the system would have large capacity, its average speed of 9 miles per hour or less with 3 platforms, is not high enough to be attractive.

Taylor's Variable Speed Moving Platform

To overcome these obstacles was apparently the object of the next attempt to secure continuous transit, which was made by Herman E. Taylor, supervisor of traffic of the Detroit (Mich.) Street Railways, who apparently began to work on it soon after the Putnam demonstration plant was built. By combining the continuous moving platform idea with the thought that was in the mind of Ebenezer Hawkins, and a drive scheme similar to the screw drive of Adkins and Lewis, he developed a very ingenious system. He proposed having 2 endless moving platforms with one of them running at a fairly high constant speed (20 miles per hour was suggested), and the other running at a speed varying from about 1 mile per hour up to the speed of the first.

The second platform was to be used to transfer passengers between the stationary and the high-speed platforms, and was to be driven so as to go through regular cycles of running at about 1 mile per hour, accelerating, running at the same speed as the high-speed platform, and then decelerating to 1 mile per hour to complete the cycle.

This scheme offered not only a high speed nonstop ride with only 2 moving platforms, but it made transferring passengers from one to the other both safe and easy by transferring them when the difference in speed was very small. It was an excellent system that was undertaken, but there are 2 serious obstacles to its commercial success:

1. Difficulties in connection with the screw drive which would appear to be almost insurmountable, and

2. The amount of power required to operate it, partly because of the inefficiency of the drive, and partly because of the large losses from accelerating and stopping the transfer platform. These losses together with the inefficiency of the screw drive and the peak loads would make the cost of power prohibitive.

The "Biway" System

The "biway" is the latest consideration in the way of continuous or nonstop mass transit for local service in congested traffic areas. The general idea of it is similar to that of the Taylor system, but there

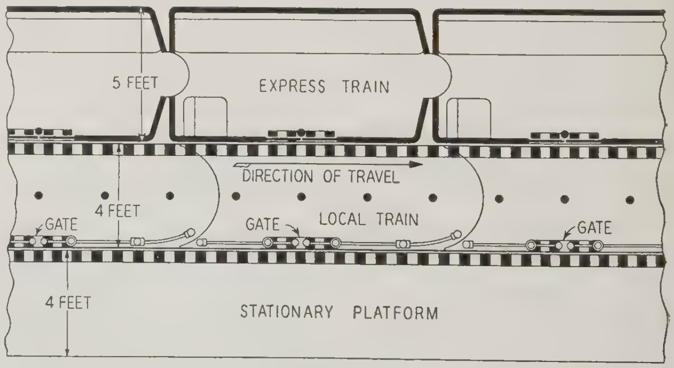

Fig. 2. Floor plan for biway system

are differences both in the results and in the means of obtaining them that are believed to make it a more practicable and economical system.

It consists of 2 endless electric platforms on parallel tracks with a stationary platform extending the entire length beside them. (See figures 1, 2, and 3.) One of the platforms—the express—moves continuously at a selected average speed (not a constant speed) with variations above and below that speed depending on several conditions that will be explained later. (See figure 4.) The other moving

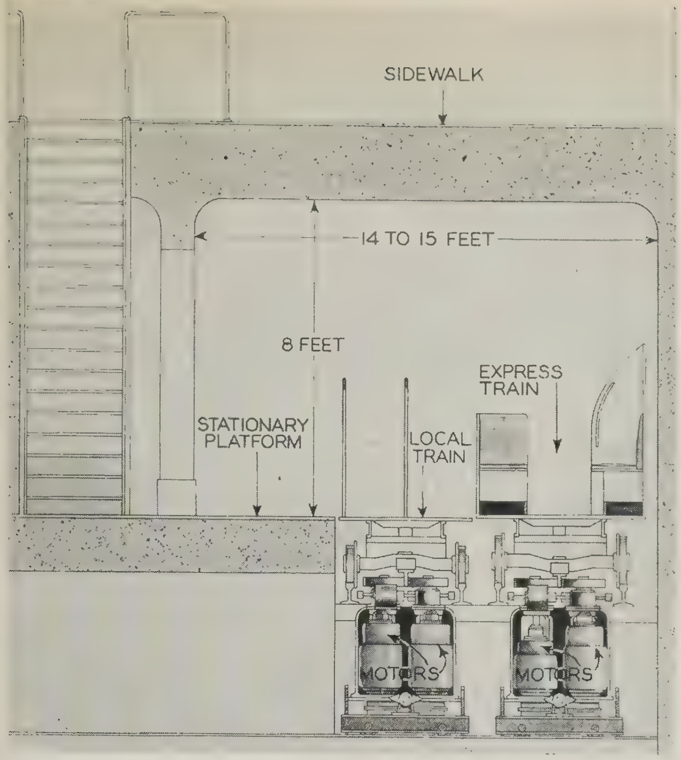

Fig. 3. Cross section of biway system

platform—the local—lying between the express and the stationary platforms, every 42 seconds goes through a regular cycle of standing still, accelerating, synchronizing with the express at its minimum speed, running at that speed for a certain number of seconds, then slowing down to a standstill to complete the cycle.

Figure 4 gives the combined speed-time curves of both platforms, showing the variations in speed of both throughout the cycle. It shows that with an average speed of 15 miles per hour, the express platform varies in speed between 16.5 and 12.5 miles per hour, while the local platform starts from rest, accelerates to 12.5 miles per hour, reaches that speed at the same time as the express, runs at approximately the same speed for 10 seconds, and then decelerates to a standstill while the express accelerates to its maximum speed. This cycle is repeated every 42 seconds as shown on the speed-time curves.

There are several reasons for the variable speed express:

1. It permits a lower maximum speed for the local, which decreases the amount of power required to accelerate it, and, with the same rates of acceleration and deceleration and the same average express speed in both cases, saves from 3 to 5 seconds in the duration of a cycle of operation over that of a constant speed express.

2. It affords a means of securing a practically constant load on the power line. This is effected by interchanging the kinetic energy of the moving platforms when speeds are changing.

3. It increases the efficiency of operation by saving energy that would otherwise have to be lost in stopping the local platform.

The amount of variation in speed of the express is dependent on the relative weights of the 2 moving platforms. The rate of change will be adjusted so as to maintain a uniform flow of power from the external circuit. These results will be obtained by a system of regeneration by which the local draws power from the express when accelerating and returns power to the express when decelerating. Incidentally, this eliminates all forms of mechanical brakes from the equipment. Emergency stops will be made by using the motors for dynamic braking.

As may be seen, the function of the express is to give every passenger a nonstop ride from where he enters the biway until he reaches his destination. The express stops only once a day. The local stops 85 times every hour. Its chief function is to transfer passengers from the stationary platform to the express, and *vice versa*. Of course, passengers may ride the entire distance on the local if they want to, but it will be noted that there is standing room only with posts or outside railing to hold on to, on the local, while the express is provided with seats, there being about 4,000 per mile, giving 60,000 seats per hour past a given point.

Wherever possible, the biway should be located under the sidewalks of the busiest streets, with easy access to it both from the sidewalks and from the principal buildings adjacent to it. Turnstiles or doors should be not more than 100 yards apart unless the biway has to be located at a low level at some points to avoid a subway or other obstruction.

The advantages of this system to the passenger are obvious: The frequent entrances; the short interval between stops; floors of stationary and moving platforms all on the same level; stepping from one platform to another either when both are at a standstill or when both are moving at the same speed; smooth and slow rates of acceleration and stopping; comparatively noiseless operation; the absence of crowding as the result of the better distribution of passengers; the practical certainty of a seat for everyone at all times; and a nonstop ride from wherever one happens to be on the line to within 200 or 300 feet of the exit one wishes to use. All these features will appeal to the passenger because they will save his time or add to his comfort and safety.

The entire line will be well lighted and much of it arcaded where it can be located under the sidewalks. Conspicuous signs give the names of buildings or streets with advice as to when the passenger should transfer to the local in order to come closest to his desired destination. The advice to transfer will be shown about 840 feet from his desired destination, and the passenger will transfer at the next opportunity. If that stops him too far short of his street, he can ride another cycle on the local which will take him about 400 feet farther. In this way, he can come very close to the desired spot.

Figure 5 shows the average speed and distance traveled in terms of cycles. Distances are plotted with one cycle only on the local, 2 cycles on the local, and all on the local. At a speed of 15 miles per hour, the express will travel 924 feet per cycle while the local travels 390 feet. The curve in figure 5 shows that one can go 5,000 feet in 6 cycles (or 4.2 minutes) giving an average speed of 13.5 miles per hour. In 12 cycles, one would travel 10,560 feet at an average speed of about 14.3 miles per hour. Both of these rates are conditioned on riding one cycle on the local and the rest on the express. It follows that the more

cycles one travels on the express, the nearer his average speed approaches 15 miles per hour. While this is not a high speed, it will compare very favorably with subway or elevated local train speeds. The greater accessibility and greater frequency of stopping will save much walking and much time ordinarily spent waiting for trains.

Figures 1, 2, and 3 give a fair picture of the general construction. As indicated on figure 2, the electrically operated platforms are divided up into short sections which will be from 8 to 12 feet long, depending on the minimum radius of curvature on the line. Each section will have only 2 wheels, which will be mounted on a fixed axle at one end of the section. The other end is carried on the axle of the next section, so that the platform is an articulated structure. In order to provide a continuous floor, whether on tangent or curved track, the ends of the sections are arcuately shaped as shown in figure 2.

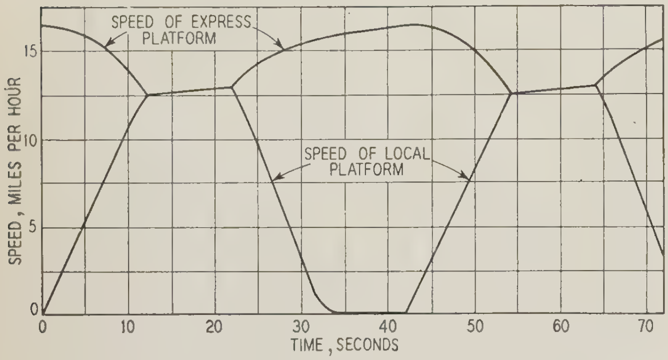

Fig. 4. Speed-time curves for the biway system

The wheels on the axles are mounted on separate roller bearings and perform no functions other than carrying the load and keeping the train on the track. The wheels may be either solid steel or some form of resilient construction. If steel tires are used, it will be desirable for the sake of reducing noise and wear to grease the track rails.

The platform section will be of a very simple and light construction which will lend itself readily to mass production as there will be from 400 to 660 sections per mile in each platform.

The Drive. The method of driving the platforms is rather novel, although the idea is an old one. It is purely an adhesion drive, but the motors are stationary beneath the tracks and the rail is carried under the platform. Figure 3 is a diagrammatic cross section of the biway showing the wheels, fixed axles, and the driving rail which, in the form of a T section like an elevator guide rail, is carried underneath the middle of the axle. The sketch also shows the driving wheels or rollers and the vertical-shaft motors that furnish the motive power. The drivers are in pairs with the flange or stem of the driving rail running between them. The necessary pressure on the drivers is obtained by compressed air. This acts on large roller bearings on the driving shafts just under the drivers, so as to pull the drivers together. The motors, mounted on trunnions to permit a slight lateral variation of the driving rail, are carried on a base frame supplied with small wheels. When in the normal position, the base frame is raised well above the floor and bolted to a solid foundation and the motors are also anchored at the top by tension rods against the reaction of the drivers.

The T section used for the driving rail is a very important element in the platform. It really forms its backbone. It is shown in figure 6 with the coupling castings welded to it with one of them including the means for securing the rail to the axle. The coupling brings the ends of adjacent rails into exact alignment on tangent track where the driving motors are located. The ends of the rails are cut off at an angle of 45 degrees for obvious reasons. The entire drawbar force is carried through this rail. In fact, if the wheels, axles, rail, and couplings were fitted together, they could be driven around the track without any floor or superstructure, whatever. This lends itself to a very simple construction since it permits easy replacement of a rail and coupling from the inspection pit, or of the floor and upper works of a section in case of a serious repair being necessary.

The driving rail is supported by the axle and clamped to it through rubber pads as shown in figure 6. This is to prevent the vibration from the driving rollers and the motor gears from being communicated to the floor of the platform.

The coupling has a universal joint of the ball and socket type. Means are provided in this coupling for taking up slack in the platform and also to allow a small amount of flexibility in it.

Driving Motors. The mechanical arrangement of the driving motors with respect to each other and to the driving rails of the 2 platforms is shown in figure 7, and the main circuit schematic diagram for the motors is shown in figure. 8. It may be noted that a set of motors for a driving station consists of 3 pairs of motors marked $M1$, MG, and $M2$, respectively. The 2 motors of each kind are connected permanently in series. The $M1$ and MG motors are geared to the driving shafts of the express platform, one of each to a shaft on either side of the driving rail. The $M2$ motors are geared to the driving shafts of the local platform. All of the motors are compound wound with shunt windings separately excited, and the series windings connected as usual in series with the armature.

While the $M1$ motors are amply able to drive the express platform, the addition of the MG motor makes it possible to have voltage control for $M2$ for accelerating and also provides means for interchanging stored energy between the 2 platforms.

The $M1$ motors are the only motors connected to the outside power line. Geared to the driving shafts for the express platform, they run continuously at a speed proportional to the speed of the express, and at a load varying only with the total weight of passengers. The MG motors are geared to the same driving shafts for the express platform, one MG motor being geared to each shaft. The $M2$ motors are duplicates of the MG and are geared to the driving shafts of the local platform.

The diagram in figure 8 shows that the MG and

*M*2 motors are permanently connected together electrically, but are disconnected when the local is standing still. All the power taken by the local platform is generated by the *MG* motors and put into the *M*2 motors. The *MG* and *M*2 motors act alternately as motors and generators; when one is acting as a generator, the other acts as a motor. They interchange current one way or the other all through the cycle except during the time the local is standing still. The *M*2 motors have a strong field practically all the time they are in operation. The field of *MG* varies all the way from 0 to its maximum strength, depending on the voltage required or supplied by *M*2.

Control. The control system for the biway is entirely automatic and when once started will continue to put the moving platforms through the regular cycles of operation until power is cut off. Each set of motors will have its own control apparatus which will be operated in synchronism with all other stations. The speeds of the motors, and therefore of the platforms, are controlled entirely by means of field rheostats. A combination of sequence drums and field rheostats is operated by a synchronous motor with power furnished from a generator at the central control station, so that all of the control sets are operated in synchronism and everything is controlled on a time basis. The generator supplying current for the synchronous motor is under the control of the central control station operator, who can change its speed and consequently the length of a cycle by simply changing the speed of its driving motor.

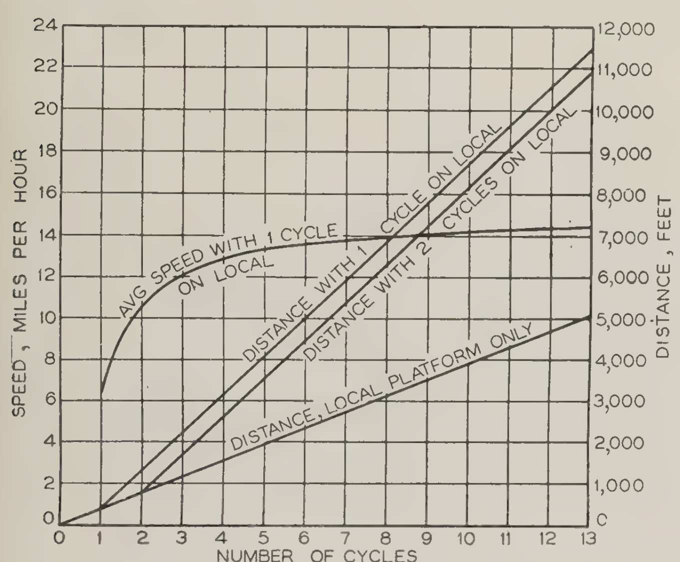

Fig. 5. Speed and distance curves for the biway system

Time of cycle taken as 42 seconds, average speed of express as 15 miles per hour

Similarly, the chief operator by a proper control of the supply voltage, can change the speeds of the platforms. By combining these 2 schemes of changing the length of cycle and the speed, he can secure almost any result desired within the capacity of the motors. This may prove to be a valuable asset in meeting various traffic conditions.

In addition to controlling the motors, the synchronous motor-operated sequence drums will open the gates and operate suitable signals to inform the passengers of the proper time to transfer.

Brakes and Train Signals. With the biway system, neither mechanical brakes nor train signals will be necessary because with continous platforms there can be no collisions and every section of the platform must run at the same speed as every other section. As previously stated, the deceleration of an electric platform is accomplished by using the motors on that platform as generators. In the ordinary cycle, the power generated by one electric platform is used to accelerate the other platform. If it is desired to stop both of them, power is cut off the *M*1 motors and the *MG* and *M*2 motors act as generators and stop the platform by dynamic braking, the power generated being absorbed by resistors.

The elimination of all mechanical brakes in this way eliminates a great deal of noise, all brake shoe dust, and saves the energy usually lost in stopping trains.

Power Consumption. It is significant that the only power taken from the external line is that required to overcome train resistance and to supply the losses in motors, drive, and control. Although the efficiency of regeneration is not high, regeneration effects a considerable saving in the total energy consumption. It is estimated that the energy consumed by this system will be in the neighborhood of 35 watt-hours per ton mile for both platforms, or from 300 to 450 kw per mile, depending on the load. This is very light when compared with street cars or subway trains. A fully-loaded 10-car train in the 8th Avenue Subway, New York, carries a maximum of 2,800 passengers, of whom only 540 are seated, and requires over 4,200 kw to accelerate it. The power consumption of the biway with a given load will increase as the rates of acceleration and deceleration and the number of cycles per hour increase. The rates recommended are from 1 to 1.25 miles per hour per second, which will be very easy for standing passengers on the local platform, and is fast enough since it does not affect the speed of the express platform. The only disadvantage of the low rate of acceleration is that it increases the length of a cycle

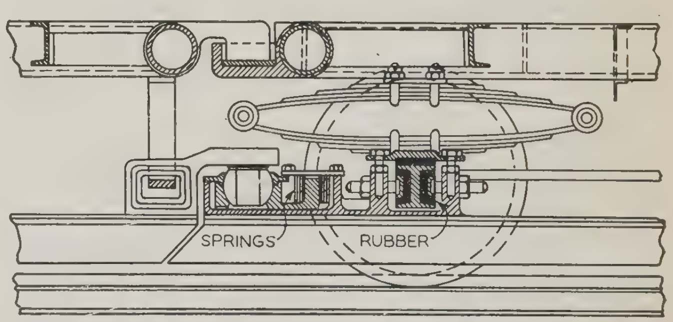

Fig. 6. Section through coupling and running gear of moving platform

and the distance covered by the express in one cycle. This can be varied over a wide range to suit local conditions.

The low power consumption and the high load factor make it possible to operate the biway during periods of light load with very little expense. It could probably be operated 20 hours per day with an average load of not more than 350 kw per mile.

Safety. Naturally the first consideration in the design of a system for city transit is for the safety of the passengers. This attribute the biway possesses to a high degree for the following reasons:

1. The maximum speed is low, scarcely more than a third of that of the subway or 40 per cent of the maximum speed of the ordinary street car.

2. The floors of the moving and stationary platforms are all on one level.

3. There is no interference or danger from other traffic as there is with street cars and busses.

4. Crowding is prevented:
   a. By receiving the passengers all along the route instead of forcing them all to enter at a few stations,
   b. By the greater frequency of stops, nearly 3 times the maximum frequency of subway trains, which prevents crowds from collecting.

5. The voltage control system used absolutely prevents jerking the train and the rates of acceleration and deceleration are very low.

6. Passing from one platform to another is done when there is practically no difference in speed between them.

7. There will be a minimum of interference in interchanging passengers because the gates will open from $^1/_3$ to $^1/_2$ the entire length of platforms, and provide ample space.

8. The gates will be opened and closed automatically to prevent passengers from transferring when there is a material difference in speed.

9. The sections of platform will be short enough to prevent any serious gaps between platforms on curves.

10. Guards will be placed at frequent intervals along the route to render assistance to any in need.

11. Emergency stop buttons will be located so as to make it possible to stop both platforms quickly from any point on the line.

12. There is no possibility of a passenger falling to the tracks since the platforms cover the entire space except for the very narrow track between them.

Reliability. Next in importance to safety on a line of this character handling large numbers of people is reliability. This is secured as follows:

1. The construction of the platforms will be simple and rugged with every part having a large factor of safety.

2. Wearing parts will be accessible for inspection and easily replaceable, most of them while the system is in operation.

3. Driving motors are stationary, located under the tracks, and can be taken out and replaced easily while the biway is in operation.

4. Control apparatus for a set of motors may also be repaired or replaced without interfering with operation.

5. Sufficient driving stations will be provided so that some of them will always be idle. Stations will be about 500 feet apart.

6. Inspection pits under the tracks will be provided at all driving stations.

7. Gate operating mechanism will be above the floor so it can be repaired or replaced while the platforms are in motion.

8. Couplings may be inspected and lubricated from above the floor.

9. The slow speeds at which the platforms are run will not only contribute to long life of parts, but will make it easy to detect deterioration that might lead to a breakdown.

Capacity. The ultimate capacity of the biway is enormous. As previously stated, there will be 4,000 seats per mile of express, or at 15 miles per hour, 60,000 seats past a given point per hour in one direction. There will be comfortable standing room for as many more. Based on the same floor space per passenger as the subway cars the express could carry 11,000 passengers per mile, or 165,000 per hour past a given point. The local can easily carry 5,500 standing passengers per mile without interfering seriously with transferring. This would make 35,000 more past a given point per hour, or a total ultimate capacity of 200,000 passengers per hour. This appears so far beyond the maximum requirements as to make it scarcely worth considering. Since much of the riding on the biway would be for short distances, the total number of passengers carried would be much greater than the number carried past a given point. There can be no question as to the capacity of the biway.

Convenience. The question of convenience plays a very important part in any transit system. In this respect, the biway located under the sidewalks is second to none. It would be accessible either from the sidewalks or through the adjacent buildings. Entrances will be provided at intervals of not more than 100 yards, so that a very few steps would always bring one to an entrance. After passing the turnstile, one would not have to wait an average of more than 16 seconds for the local to stop. After boarding the local, his average speed will depend on the distance he goes and the number of cycles he rides on the local. He will make an average speed that would be impracticable on a car making the same number of stops per mile, even when accelerating and braking at 4 times the rate of the biway. The biway will be comfortable as well as convenient and relatively fast.

Heating. The biway will be heated in the winter, either by steam where that is available, or by electricity. The entrances will be protected by doors to prevent loss of heat, but since the passengers will be dressed for the street, it will not be necessary to have a temperature above 60 degrees Fahrenheit, and probably 50 degrees would be ample.

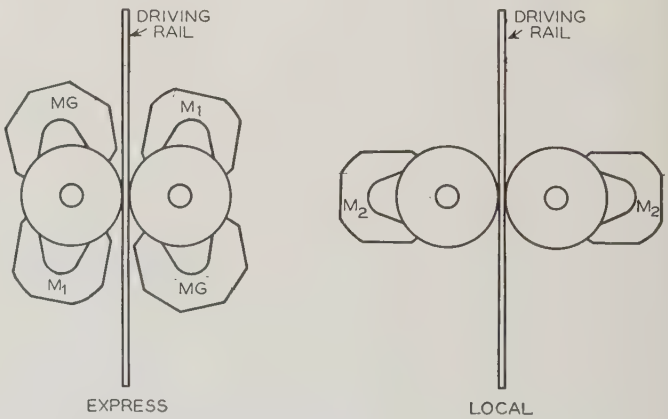

Fig. 7. Arrangement of one set of driving motors

Costs. The cost of a biway system is dependent largely on local conditions which govern the costs of

real estate, excavations, etc., which will be the largest factor in the first cost.

The biway for one direction will require about the same size of tunnel as a single track subway, but will be wider and not so high. On that basis, estimates made from actual costs of subways indicate

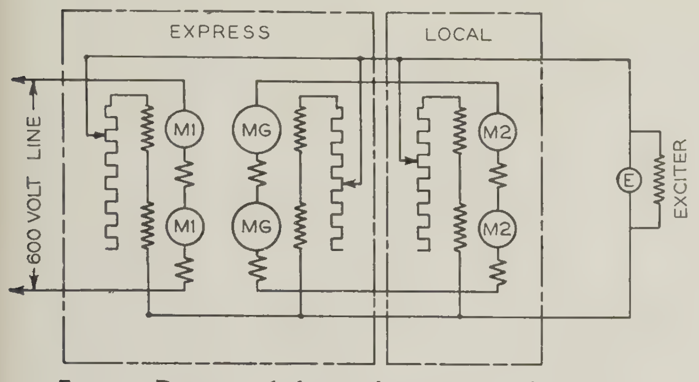

Fig. 8. Diagram of electrical connections for driving motors of the moving platforms

that the total cost of biway ready for operation will lie between $3,500,000 and $4,500,000 per mile, or $10,500,000 to $13,500,000 for a 3 mile loop. At six per cent, the annual charges will be from $630,000 to $810,000.

The annual operating costs are estimated to be approximately $615,000 for a 3 mile loop. It will require about 34,000 passengers daily at 5 cents each to pay this. 45,000 passengers daily will pay the interest charges, so that only 79,000 passengers daily would be required for interest and cost of operation.

Operating Economies. A comparison of the biway with the New York Eighth Avenue Subway will serve to point out the difference in costs. As stated, the biway will require a tunnel with about the same cross section as a single track of the present subway. It would cost more to finish and light it. The tracks would cost somewhat more for permanent resilient supports, which are desirable, and for the double track which, however, would not have heavier than 45 pound rails, while the subway would have at least 90 pound rails.

The biway express would weigh about 440 tons per mile; the local about 325 tons, or a total of 765 tons per mile. This weight is equal to that of 18 subway cars. This number of cars can seat 972 passengers. One mile of biway would seat 4,000. Eighteen cars can carry a maximum of 5,040 passengers. One mile of biway could carry conservatively a maximum of 12,000. It would, therefore, require at least 40 subway cars to equal in capacity one mile of biway. Forty cars weigh 1,700 tons as against 765 tons for the biway.

Forty cars have motor capacity of 380 horsepower per car or a total of 15,200 horsepower. One mile of biway will require less than $^1/_4$ this horsepower in motor capacity, including spare motors on the line. Even this is out of all proportion to the power taken from the line, on account of having extra motors and larger sizes for regenerating. The motors will be located in 10 driving stations with 6 motors per station. The mounting and driving mechanisms of the motors for the biway will probably cost as much as the motors themselves, and the construction of the driving stations will add still more so that the difference in cost of motive power will probably not be very great.

There will be a great difference between the cost of 40 subway cars without propulsion equipment, and one mile of biway. The latter will be a mass production proposition of very simple parts, and, considering that the weight will not exceed $^2/_3$ of that of the subway cars and trucks, should not cost more than half as much.

When it comes to power consumption, the difference will be still greater. It must be understood that it is utterly impossible for the subway cars to make 13.5 stops per mile and maintain a schedule speed of 12 to 14.5 miles per hour as the biway can do (see figure 5). Even with 2 $^1/_4$ stops per mile, the subway trains can maintain a speed of only 14 miles per hour with 73 watt-hours per ton mile—double the watt-hours per ton mile required by the biway. A street car making 9 stops per mile with a schedule speed of 14 miles per hour will require about 325 watt-hours per ton mile—about 4.5 times the amount taken by the subway with the same speed and $^1/_4$ the stops per mile. With only 3$^1/_4$ stops per mile, the subway cars would require about 3 times the watt-hours per ton mile that the biway would. Thus even with reduced service in the subway during the light hours of traffic, and the biway running at normal speed, the biway would not use more than half as much power as the subway. If it is desired to reduce the cost of operation of the biway during the night hours, the speed may be reduced to 8 or 10 miles per hour, and would probably give better service then than the subway with fewer trains.

Altogether it appears that the biway will cost less to construct and install than the subways and will give much better service.

The Field for the Biway

Undoubtedly the initial field for the biway lies in the crowded districts of large cities where it should be used for local transit and for distributing passengers from outlying districts. A set of interconnecting loops through the busy section would enable a passenger to reach any part of the section quickly and easily. There are strong possibilities that it might supersede the present local trains of the 4-track subways. A test in actual service is necessary to prove its suitability for the service and its possibilities for extensions to longer lines. Such a test can be undertaken only by a properly financed transit utility or by a muncipality, since the installation would involve the right of way, interferences, and a cost of construction far beyond what could be financed by a manufacturer of the equipment itself. When such a test has been made, the costs of operation, power, and maintenance will be determined and all questions as to safety, reliability, and general practicability will be answered. Certainly, if cities continue to grow, a system having the characteristics and attributes of the biway will soon be an absolute necessity.

Silicon Steel in Communication Equipment

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Steel containing small amounts of silicon has come into wide use as a magnetic core material. In this paper the different grades of silicon steel, and other magnetic materials such as the nickel-iron alloys, are discussed with particular reference to the selection of the most satisfactory alloy for the various applications in communication equipment, which includes transformers for audio frequencies, small rotating apparatus and relays.

Of THE 10 elements which form nearly 99 per cent of the earth's crust only oxygen is more abundant than silicon, the availability of which makes it inexpensive as compared to other alloy elements. It is doubtful if iron or steel has ever been produced commercially without at least a trace of silicon. In the proper proportions it indirectly increases the initial permeability and decreases losses, but with a reduction in saturation induction slightly greater than the percentage of silicon added.

The early work of Hopkinson, Parshall, and Hadfield dealt with the study of the magnetic and electrical properties of silicon alloys and directed attention to the possible application of such alloys and magnetic structures.[3] The first silicon alloy sheet was produced shortly after 1900 by several German firms for the Physikalisch-Technische-Reichsanstalt. As was expected, because of its higher specific resistance, eddy current losses were reduced, hysteresis losses were also lower, and permeability in low fields was higher than for ordinary iron. The records of the General Electric Company indicate that it was 1905 before silicon steels were regularly used in transformers. Development has continued and improvements are still being made. In figure 1 is shown the decrease in core loss of commercial silicon steels during the period 1905 to 1933.

Silicon Steels

There are available commercially in the United States 6 grades of electrical sheet steels whose normal properties are given in table I and in figures 2 and 3.

It is common practice to purchase steels containing one per cent or more of silicon on the basis of magnetic and mechanical tests but with no definite specification as to silicon content. Sheet steels are processed by the manufacturer by treatments such as hot and cold rolling, annealing, pickling, etc., in any desired sequence depending on the requirements. Many manufacturers of the higher grades of silicon steels reclassify them depending on the losses as measured during the manufacture. For example, a 29 gauge steel sheet containing a given percentage of silicon may be sold under a loss guarantee, for use at 60 cycles with flux density $B = 10{,}000$ lines per square centimeter, of 0.72, 0.66, or 0.60 watts per pound. Maximum permeabilities are available from 5,000 for standard iron to 8,000 for the ordinary transformer irons and 20,000 for the best silicon transformer irons.

In order to select the proper grade of material for a particular application, a number of factors must be considered. For example, standard and armature grades of steel have rather high losses and are subject to aging, or gradual change in magnetic properties at operating temperatures, while steels of higher silicon content do not age. Steels with low silicon content are difficult to mill anneal because of sticking during the process, and further, the low resistivity is objectionable except at low frequencies. Thus standard iron and armature iron are undesirable where efficiency is important; however, these may be used to advantage where low cost is essential, the service is intermittent, or the apparatus requires a high saturation limit and uses low frequency. Unlike standard iron, armature iron is sold by the mills on a guaranteed loss basis, and this, together with the expense of the better annealing, makes an appreciable difference in price.

Electrical sheet containing approximately 1 per cent silicon, is the cheapest reliable grade of mill-annealed steel and so is widely used for low frequency and low cost machines where efficiency is not highly valued. Its mechanical properties are very similar to standard iron although it has slightly more surface scale. It is suitable for use in rotating apparatus.

Motor grade, about $2^1/_2$ per cent silicon, is thoroughly reliable mechanically as well as magnetically. It is particularly suitable for use in medium sized rotating apparatus and in certain classes of transformers and reactors. It normally has an appreciable surface scale which may be satisfactory as insulation in small apparatus. It can be spot welded.

Dynamo grade, which contains $3^1/_2$ per cent silicon, is considered satisfactory mechanically for general use in rotating apparatus but with higher silicon content brittleness makes such use hazardous in the rotating parts. On account of the normal heavy

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3. For numbered references see list at end of paper.

scale of this steel annealing in a neutral atmosphere is necessary to prevent oxidation, and it is often better to purchase this material pickled. Punching of the mill-annealed dynamo steel hardens the edges sufficiently to prevent tearing when used in transformers having a forced fit core where motor grade normally is too soft.

For large transformers, where size and losses are limiting factors, transformer grade with 4 per cent or more of silicon will give uniformly low losses and annealing can be done after punching in a forced fit core design without fear of tearing. Transformer grades of steel are used particularly for apparatus where low losses without particular regard to mechanical properties are necessary. Transformer steel which has been selected for lower than normal losses is additionally classified as audio grade.

These grades of material are further classified as to thickness, the most commonly used gauges being 24, 26, and 29. For power use 29 gauge is about as thin a sheet as is practicable from consideration of manufacturing, resulting loss, and cost. For frequencies from 2,000 to 10,000 cycles 36 gauge and for radio frequencies 3 mil stock is used. Space factor punching and assembling costs, expense of dies, extra rolling, and increasing core losses limit the thinness of steel for a given application. However, it has been found that unless the frequency exceeds 2,000 cycles, the 29 gauge is, in general, the most economical.

Besides selecting the grade and thickness of steel to be used, the designer is faced with some interesting problems in selecting treatment for the steel. For lowest cost, annealing at the mill, punching, and assembling without any factory treatment is the appropriate procedure. For high frequencies, low flux densities, and small tooth widths and air gaps it is important to anneal the material after punching in the factory. Special technique is required in annealing to minimize warping to secure the least possible surface scale, and to obtain the lowest possible hysteresis losses. Surface scale on silicon steel is very objectionable, not only because it causes rapid die wear, poor space factor, and loose particles, but because it materially increases the core losses at high induction. Best results are obtained by annealing in hydrogen and subsequent pickling, but this process is too expensive for general use.[13]

It is important to secure minimum burrs on the punched edges and it is occasionally desirable to lightly grind off these burrs before assembly. Insulation of the punchings is more necessary at high frequencies and in large apparatus, but it can usually be dispensed with on the silicon steels used in small radio and audio apparatus.

Other Magnetic Materials

There are a number of special and experimental alloys which should be mentioned to make any consideration of magnetic materials used in communication equipment complete. For radio frequency use there has been developed a powdered iron which is molded in a binding material which insulates each particle. At present this material is used to make cores for intermediate frequency transformers used in some radio receivers and its possibilities appear quite favorable, particularly from the standpoint of reducing the size of these transformers. A similar material has also been successfully used for the cores of telephone loading coils.

Where lower losses and higher permeabilities are required than can be obtained in silicon alloys, the nickel-iron alloys, or permalloys, are very useful. A 45–50 per cent nickel alloy is used in certain classes of audio transformers, and in other devices where a high saturation limit is not required. This material of 29 gauge can be obtained commercially with losses under 0.35 watts per pound at 60 cycles with $B = 10{,}000$. Commercial maximum permeabilities are in the order of 45,000 to 60,000. However, the cost of this material is from 6 to 10 times that of the best grades of transformer steel and of necessity it must be factory annealed after punching. However, the mechanical properties are much better than those of the highest grade silicon steel so manufacturing losses are not as great.

A permalloy which contains approximately 80 per cent nickel has about $1^1/_2$ times the permeability of the 45–50 per cent nickel alloy but the cost is twice that of the latter. Both of these alloys have the disadvantage that magnetic properties change adversely due to mechanical shock or stress, a characteristic which must be given due consideration. Permalloy has been used very successfully for loading extremely long cables such as transatlantic telegraph cables.

Table I—Properties of Electrical Steels

	Grade					
	Standard	Armature	Electrical	Motor	Dynamo	Transformer
Normal silicon, per cent....	0	0.5	1.0	2.5	3.5	4.0r
Watts loss per pound at 60 cycles for 29 gauge as purchased, B = 10,000...	2.1	1.65	1.35	1.10	0.95	0.70
Flux density in lines per square inch at 100 ampere turns per inch......	105,000	105,000	105,000	100,000	100,000	96,000
Number of 180 degree bends over 5 millimeter radius to cause fracture, 29 gauge..............	20*	20*	21	16	8	2
Ultimate strength in pounds per square inch...	42,000	45,000	47,000	60,000	70,000	80,000
Yield point in pounds per square inch............	28,000	27,000	27,000	47,000	57,000	69,000
Elongation in 4 inches, per cent..................	21	19	17	12	4	3**
Resistivity approx. microhms per centimeter cube..................	14	18	25	43	51	62

* These figures are for 26 gauge (0.019 inch). The values for these materials are quite variable.
** Elongation in 2 inches, per cent.

Application of Silicon Steel

The selection of the grade of magnetic material best suited to the component parts of communication equipment depends primarily on the limitations im-

posed, such as size and weight, losses, voltage regulation, and cost.

Power transformers operate at only one frequency, such as 25, 50, or 60 cycles, although there are special cases where 360, 500, or 800 cycles are used. For the 3 higher frequencies 29 gauge transformer steel is generally used since it has the required high resistivity which limits losses to a satisfactory value. However, for the lower frequencies each limitation must be considered separately.

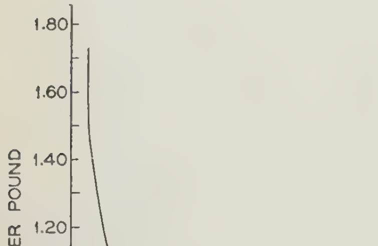

Fig. 1. Improvement in quality of silicon steel as indicated by reduction of core loss

Loss for 29 gauge steel at 60 cycles with flux density of 10,000 lines per square centimeter

On high class transmitting equipment the limiting factors are usually voltage regulation and losses. Thus the higher silicon content steels are desirable since for a given loss they can be operated at higher densities, thereby allowing a reduction in core cross section and reducing winding resistance and leakage reactance.

Power transformers or other special apparatus used on ships and airplanes invariably must be made as small and light as possible and hence require the use of a lower loss material such as transformer steel (audio grade). Those used in broadcast receiving equipment, however, are usually built in larger quantities and cost is a more important item. The grade of steel to be used depends more on the relative importance of each limiting factor and also on the manufacturer's plant equipment. Consequently, the 24 gauge motor grade, both the 24 and 26 gauge dynamo grade, and the 29 gauge transformer grade either mill annealed or factory annealed may be used as requirements dictate.

In general, the same factors that control the design of power transformers apply in the design of reactors but have different relative weights in the selection of the material, depending on the function of the reactor. The low frequency filter reactor, for example, operates at an extremely low alternating flux density so the core losses are relatively unimportant. However, the inductance of the reactor must be high to furnish a high impedance to the fluctuating current of a rectifier while the resistance must be low in order to obtain good d-c regulation. Since inductance is directly proportional to the effective permeability of the magnetic path, the permeability is an important factor in the design. The air gap which is introduced in the magnetic circuit to prevent saturation of the core with d-c flux reduces the effective permeability. Consequently, although there is an appreciable difference in the permeabilities of the various commercial silicon steels, there is a relatively small difference in the effective permeability between the motor grade and a higher grade when an air gap is placed in the magnetic circuit. As a result the use of the higher grade of steel is not justified from an economic viewpoint although limits on size and weight may justify its use.

Tank circuit oscillator reactors for use in audio oscillator circuits are distinctly an a-c type of reactor which operate at a given relatively high frequency. If the frequency is 2,000 cycles or above, the eddy current losses in the steel become excessive unless an exceptionally thin lamination of high resistivity material is used. It is, therefore, usually necessary to use a 36 gauge transformer steel in the core.

Audio reactors, like filter reactors, carry direct current but differ from the filter and tank circuit reactors in that they operate over a wide range of frequencies instead of operating at a fixed frequency, the limits depending on the range of the apparatus in which they are used. The audio reactor should have a uniformly high impedance over its entire frequency range and consequently the distributed capacity of its windings as well as its inductance must be given consideration, since the combined impedance of these 2 factors is the net impedance. As the inductance, which varies with the square of the number of turns, should be very high and since the distributed capacity, which in general increases with the number of turns and the size of the coil, should be very low, it is necessary to compromise on the number of turns and use a high permeability steel. Usually the requirements listed make it necessary to use a 29 gauge transformer steel (audio grade) in audio reactors although in special low cost apparatus, with a narrow frequency range, either motor grade or dynamo grade may meet the requirements.

Selection of Core for Audio Frequency Transformers

The audio frequency transformer has little in common with the power transformer. The power transformer operates from a voltage source of good regulation which permits a design having relatively high losses. The audio transformer, on the contrary, operates from a voltage source of poor regulation, varying widely in amplitude, and covering a wide frequency range (nominally 30 to 10,000 cycles). As a result the flux densities vary from negligible values at 10,000 cycles to approximately 4,000 lines per square centimeter at 30 cycles. Under these conditions it is desired that the transformer have a constant ratio over the operating frequency range. While such performance is obviously impossible it can be approached by providing sufficient primary

impedance, selecting the turn ratio to properly reflect the load and by correctly balancing the leakage reactance and distributed capacity in the secondary winding.

In order not to unnecessarily load the voltage source the transformer open circuit primary impedance must be equal to or greater than the impedance of the voltage source and losses in the transformer must be kept low. Since the permeability of magnetic materials decreases with the flux density (below the point of maximum permeability) this impedance should be determined at the lowest operating signal voltage and frequency. The primary impedance of the interstage or input transformers, operating with no d-c flux in the core, varies with the square of the primary turns making it desirable to use a large number of turns. The high frequency requirements, however, demand that the distributed capacity and leakage reactance of the secondary windings be kept low so that series resonance between them will not occur in the operating frequency range. Since the secondary leakage reactance varies with the square of the secondary turns and the turn ratio is fixed by the respective circuit impedances, there are 2 conflicting demands: one for a large number of turns, and the other for a small number of turns. The primary impedance also varies with the permeability and with cross section of the core, making it possible to obtain the required primary impedance by the use of a high permeability core of the proper cross section.

From the foregoing it may be seen that the characteristics of the materials used are of vital importance and that the higher the permeability of the steel, especially at lower densities, the better it is for interstage and input transformer design requirements.

If the output transformer operates from a single tube, the direct current usually passes through the primary winding and it is necessary to insert an air gap in the core to prevent saturation by the d-c flux. The output transformer is normally a step down transformer which makes it possible to use a large number of primary turns without introducing difficulties with high leakage reactance. Since the distributed capacity of the secondary winding with so few turns is negligible no consideration need be given to balance between leakage inductance and distributed capacity. Consequently, as far as core material is concerned, the same factors that influence the filter reactor design must be considered for the output transformer which carries direct current in its primary winding. The push-pull output type of transformer design can be considered as an a-c reactor operating over a wide frequency range.

In all audio transformers the operating core densi-

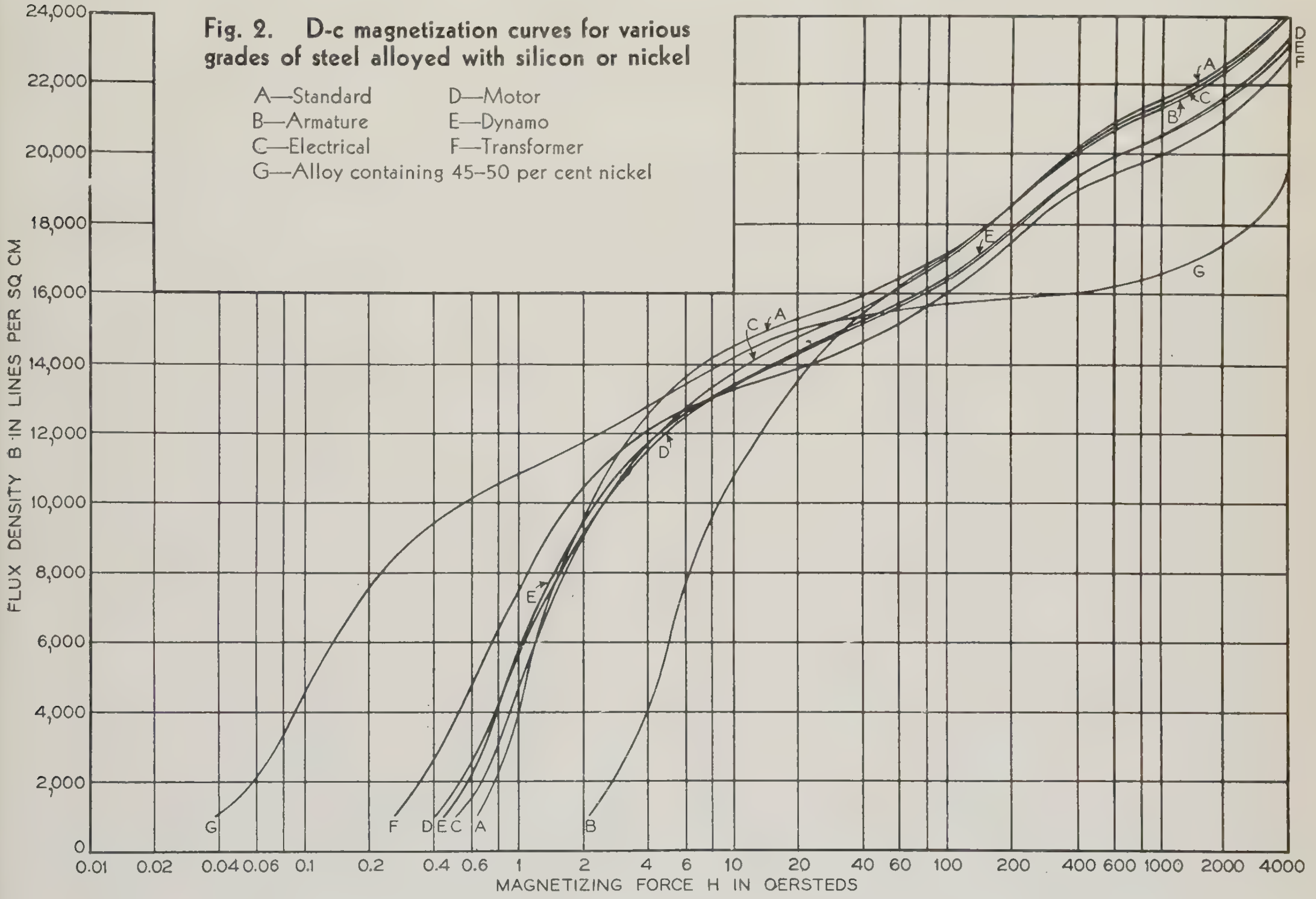

Fig. 2. D-c magnetization curves for various grades of steel alloyed with silicon or nickel

ties are kept very low and this condition combined with thin laminations and a high resistivity steel to restrict the eddy current losses at high frequencies adequately provides for the low loss requirements.

The silicon steel which best meets the requirements of high permeability and high resistivity is the transformer grade. In practice, transformer steel (audio grade) is used except in low cost receiving equipment output transformers having an air gap in the magnetic circuit. In these latter transformers to keep the cost low either motor or dynamo grade is used, but at a sacrifice in quality.

Application of Nickel-Iron Alloys

As previously indicated, a compromise between the requirements of high primary impedance and low leakage reactance and distributed capacity must be made. The primary turns are thus limited for any given design, and if a transformer steel core is used it is necessary to have a relatively large core cross section to obtain sufficient primary inductance.

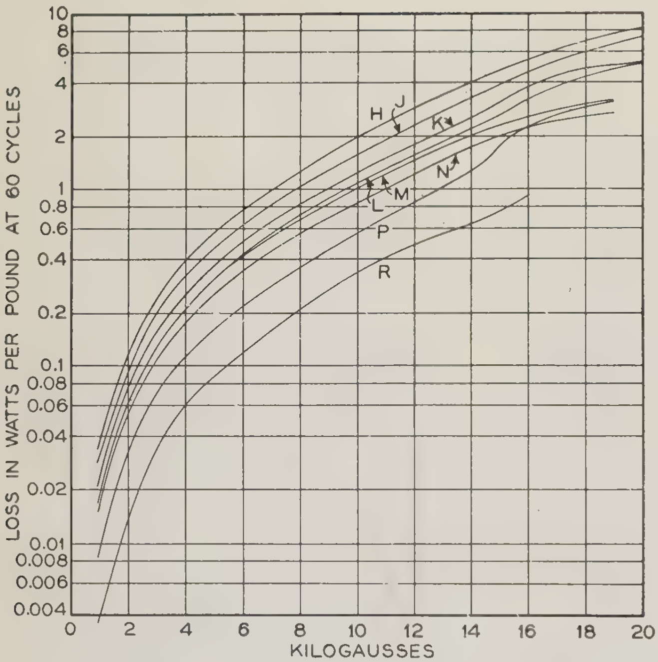

Fig. 3. Representative core loss curves for sheet steels

H—Standard, 24 gauge
J—Armature, 24 gauge
K—Electrical, 26 gauge
L—Motor, 24 gauge
M—Motor, 26 gauge
N—Dynamo, 29 gauge
P—Transformer, 29 gauge
R—Alloy containing 45–50 per cent nickel, 28 gauge

If an attempt is made to reduce the over-all physical size of the transformer by reducing the cross section the turns must be increased and it then becomes necessary to sectionalize the coils to keep the leakage reactance and distributed capacity low. The result however, is a tendency to further increase the size of the transformer rather than decrease it because of the poorer winding space factor. To obtain a size reduction it is, therefore, apparent that a core material of much higher permeability is needed to permit the use of relatively few primary turns.

With such a very high permeability steel the core section area could be reduced, and with the resulting smaller core, lower distributed capacity and leakage inductance could be obtained because both depend on the physical size of the coil. Consequently, the higher the permeability of the steel can be made the better it is for the audio transformer design, providing, of course, that the losses are also proportionally lower.

An alloy containing from 45 to 50 per cent nickel meets the requirements of both low loss and high permeability at low densities and for that reason is being used extensively although its high cost tends to limit its use. This seems to indicate that it should be used only where small size is required but actually under certain conditions of design of the larger audio transformers the additional complication resulting from the necessity of excessive splitting up of coils in silicon steel core transformers makes the nickel alloy design not only smaller but also less expensive. The steel companies have been making great efforts to improve their high silicon steel. Although there is no present expectation of reaching the nickel alloy quality, developments indicate that a new field for audio transformer design may be opened up as permeabilities are obtained ranging well above that of the commercial transformer steel.

The curves of figure 4 taken on an input transformer designed for use with a 45–50 per cent nickel alloy core indicate the relative characteristics of some experimentally improved grades of transformer steels and the nickel alloy. The same conditions were held for each curve with the single exception of changing the core material. These curves indicate very well the comparative improvement obtained in an audio transformer by using the experimental iron. As would be expected the greatest difference appears at the lower frequencies.

Application to Rotating Apparatus and Relays

While the most interesting and varied applications of silicon steel are in connection with transformers and reactors, the subject would not be complete without discussing briefly the application of silicon steel to rotating apparatus and to relays. In rotating apparatus, an air gap is necessary for mechanical reasons, and as a result of this air gap the permeability of the iron is not of particular consequence for the same reasons as discussed under low frequency filter reactors. However, the flux density in a rotating machine is relatively high; therefore, the core losses are important, and for this reason it is desirable to use a high grade of steel.

In practically all rotating apparatus for communication work built in fractional horsepower motor frames, the motor grade steel is found preferable. The thicknesses used vary from 24 gauge for the usual power frequencies down to 29 gauge for frequencies up to 2,000 cycles, and 36 gauge for still higher frequencies.

The chief consideration in selecting the steel for these small machines is to balance the efficiency

against the cost, as heating due to iron losses is seldom important. The flux densities used are kept well below saturation to minimize the excitation ampere turns consumed in the steel. The densities are reduced for the higher frequencies to keep down the total losses.

The larger rotating machines used in communication work, such as battery charging generators, high voltage d-c generators for radio broadcasting power supply, etc., present no unusual features, so far as their steel is concerned. An interesting special case, however, is that of the 15,000 to 30,000 cycle Alexanderson alternators built about 20 years ago for some of the first transoceanic radio stations, for which a special 1.5 mil standard iron was used in strip form.

The magnetic design of relays and contactors presents an entirely different problem from that of other apparatus, as the important thing here is to have low magnetic retentivity, so that the device will not be held in a closed position by residual magnetism when the circuit is opened. Many special grades of steel of low retentivity have been developed but careful annealing is required to make this property permanent. Hardening of contactor steels, resulting from the hammering of repeated operation, tends to increase the retentivity of the steel, and so makes a wide margin of safety necessary in new designs.

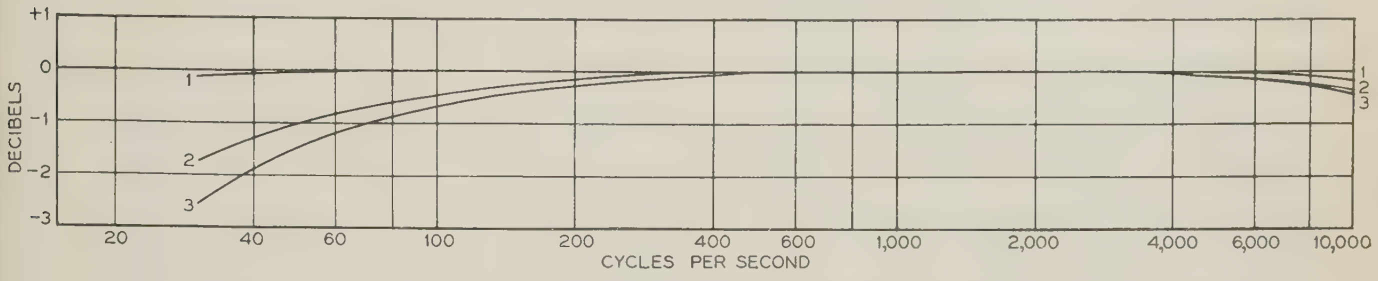

Fig. 4. Curves showing the effect of different materials on the frequency response of an audio transformer

1—Alloy containing 45–50 per cent nickel 2—Experimental iron 3—Transformer steel, audio grade

Outlook for the Future

The present trend in the development of magnetic steels is toward the use of a great variety of special alloys for new applications. Thermomagnetic steels, which lose their magnetism sharply at a certain temperature, are increasingly employed for thermal control relays and for temperature compensation purposes. Other steel alloys with aluminum, nickel, and cobalt are being developed for use as permanent magnets. These magnets make possible the design of more compact synchronous motors and small high frequency generators formerly provided with exciting coils.

Experimental work in laboratories as well as data published by the steel manufacturers indicate that future developments may be expected to yield further improvements comparable with those already obtained. The experimental steel to which we have previously referred may become a competitor of the 45–50 per cent nickel alloy and may even surpass it when used where high electrical resistivity is important. The cost will, no doubt, be very much less than that of nickel alloys. The promising success obtained by the Smith process[1a] and developments described by Goss[1] in producing cold rolled strip may be the forerunner of a still better quality and more economical method of manufacture. The one development upon which there seems to be little or no progress is that of producing a commercial material which saturates at a higher density with a low exciting current. One must not forget standard iron as more economical materials are demanded, since development work on it indicates the possibilities of replacing the lower grades of silicon steel with this cheaper material. A great variety of other alloys are being experimented with, in the hope of developing new varieties of steels with improved characteristics of loss, permeability, and other magnetic properties, and marked progress has been made.

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Research Work in Magnetics—1933–34

A review of the research work which has been done in the field of magnetics during 1933 and 1934 is contained in the articles and papers referred to in a comprehensive bibliography which has recently been prepared. In this bibliography, which is divided into 31 sections and contains 211 items, publications of all countries are considered. The list should be of considerable value to those interested in magnetics. It is preceded by an introduction which outlines briefly the trends and the developments in magnetics at the present time.

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THE causes of ferromagnetic phenomena are largely a mystery and the laws governing them are mostly empirical. This is a challenge to the physicist and engineer, which results in an enormous amount of experimental and theoretical work. Moreover, these magnetic phenomena must be correlated with the new theories of physics such as quantum mechanics, wave mechanics, and electron spin, if these theories are to be proved valid. The large number of references to theoretical investigations and to a study of phenomena chiefly of theoretical interest, such as the Barkhausen effect, Heusler alloys, properties of thin films, gyromagnetic effects, and the like, indicate the interest in this subject.

Much valuable progress has been made recently toward unified practice all over the world with reference to magnetic definitions and symbols, due to the activities of the International Electrotechnical Commission and associated bodies.

Further experimental data have become available on the a-c ferromagnetic properties of materials as a function of superposed direct current. This is of value to designers of audio frequency transformers and to rotating machine designers.

When a knowledge of the magnetic properties of single crystals became available a few years ago, it proved very valuable in furthering an understanding of the properties of ordinary polycrystalline materials. This knowledge when applied to the effects of mechanical working and heat treatment promises to be of considerable commercial importance.

Especially prepared for ELECTRICAL ENGINEERING under the auspices of the A.I.E.E. committee on research. Manuscript submitted July 11, 1935; released for publication Aug. 20, 1935.

The magnetic properties of ferromagnetic materials at moderate inductions are profoundly affected by mechanical stress. Much useful work in the field of magnetostriction has been done recently, both from a theoretical and practical standpoint.

Recent developments of commercial magnetic materials have followed several major directions: (1) new core materials suitable for radio frequencies; (2) new nickel-iron alloys with high initial and maximum permeabilities; (3) production and study of the properties of sheet with preferred grain orientation; and (4) the discovery of a number of new permanent magnet materials having remarkably high coercive forces. The chief activities on the last item have been in Japan. While most of these newest permanent magnet materials cannot be forged they mark a very great advance and at least one type of alloy will be much cheaper than the well-known high cobalt steels.

Nearly everyone working in the field of magnetics seems to feel called upon to develop new methods of test. Some of these are desirable because of new materials having properties outside of the range of previously existing materials and some are desired in order to increase the speed and accuracy of measurement or both. In the first class the newly developed permanent magnet materials have required the construction of new permeammeters which will supply higher magnetizing forces without undue heating. For the measurement of the a-c magnetic properties of laminated materials one of the most interesting new devices is the "ferrometer" developed by the Siemens-Halske Company. This measures permeability and losses by means of d-c instruments supplied through vibrating mechanical rectifiers. It also traces hysteresis loops.

The bibliography which follows covers, in general, the published articles on research work in magnetics appearing in 1933 and 1934. In its preparation, very considerable use was made of *Science Abstracts* for these 2 years. In general, diamagnetic and paramagnetic materials have been omitted.

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64. R. M. Bozorth, *Phys. Rev.*, v. 42, 1932, p. 882–92. Develops theoretical curves of magnetization and shows the agreement with published results for iron and nickel crystals.

65. R. Gans and E. Czerlinsky, *Ann. d. Physik*, v. 16, No. 6, 1933, p. 625–35. Give theoretical magnetization curves derived for cobalt, iron, and nickel crystals and compare these with experimentally observed data.

VIII—Magnetostriction and the Effect of Mechanical Stress

66. F. Preisach, *E.N.T.*, v. 9, 1932, p. 334–40. Presents theoretical and experimental work on the shape of the hysteresis cycle as a function of stress.

67. C. W. Heaps, *Phys. Rev.*, v. 42, 1932, p. 108–18. Presents data on the effect of strain on magnetostriction and the magnetization of nickel wire.

68. N. Akulov and E. Kondorsky, *Zeits. f. Physik*, v. 78, No. 11–12, 1932, p. 801–7. Give a theoretical discussion of the magnetostriction of single crystals.

69. N. Akulov, A. Helfenbein, and N. Byczkov, *Zeits. f. Physik*, v. 78, No. 11–12, 1932, p. 808–14. Present a theoretical and experimental study of the shape of the magnetization curve in weak fields as a function of elastic deformation.

70. H. Kühlewein, *Zeits. f. techn. Physik*, v. 13, No. 11, 1932, p. 539–40. Discusses magnetic "after effects" resulting from strain of very small loads.

71. A. Schulze, *Zeits. f. Physik*, v. 82, No. 9–10, 1933, p. 674–83. Discusses the linear relation between magnetostriction and the square of the intensity of magnetization.

72. M. Kersten, *Zeits. f. Physik*, v. 85, No. 11–12, 1933, p. 708–16. Discusses the effect of magnetization on the elasticity of ferromagnetic materials.

73. F. Bitter, Elec. Engg., v. 53, Sept. 1934, p. 1246–50. Offers a discussion of magnetic theory as it relates to magnetostriction.

74. W. Janovsky, *Zeits. f. techn. Physik*, v. 14, No. 11, 1933, p. 466–72. Describes test apparatus and discusses the effect of various types of mechanical stress on the hysteresis loop of ferromagnetic materials.

75. G. Tammann and H. J. Rocha, *Ann. d. Physik*, v. 16, No. 7, 1933, p. 861–4. Present test data on the change in induction of iron-nickel alloys, due to cold drawing of wire and recovery from heating.

76. R. L. Steinberger, *Physics*, v. 4, 1933, p. 153–61. Determined the magnetic properties of iron-nickel alloys under hydrostatic pressure up to 12,500 kilograms per square centimeter.

77. Y. Masiyama, Tohoku Univ. *Sci. Reports*, v. 21, 1932, p. 394–410. Presents data on the magnetostriction of iron-cobalt alloys.

78. S. R. Williams, *Rev. Sci. Instruments*, v. 3, 1932, p. 675–83. Presents data on the magnetostriction of iron-cobalt alloys.

79. Y. Masiyama, Tohoku Univ. *Sci. Reports*, v. 22, 1933, p. 338–52. Presents experimental data on the magnetostriction of nickel-cobalt alloys, covering both the longitudinal and transverse effects.

80. F. Preisach, *Phys. Zeits.*, v. 33, 1932, p. 913–23. Gives experimental data of permeability and hysteresis by magnetization in the direction of applied tension, including some information on Barkhausen discontinuities.

81. R. Becker, *Phys. Zeits.*, v. 33, 1932, p. 905–13. Gives a theoretical discussion of elastic tension and magnetic properties

82. T. Aizawa and G. Wachi, Electrotech. Lab. Tokyo, Japan, Researches, *No. 351*, 1933. Present experimental results on the effect of tension on the magnetic hysteresis of "permalloy."

83. O. v. Auwers, *Ann. d. Physik*, v. 17, No. 1, 1933, p. 83–106. Presents experimental data on the influence of the intensity of magnetization upon the modulus of elasticity and damping of natural vibrations of ferromagnetic materials.

84. R. Becker, *Zeits. f. Physik*, v. 87, No. 9–10, 1934, p. 547–59. Gives a theoretical discussion of magnetostriction of ferromagnetic ellipsoids.

85. M. Kornetzki, *Zeits. f. Physik*, v. 87, No. 9–10, 1934, p. 560–79. Examines the theory of magnetostriction of ferromagnetic ellipsoids from an experimental standpoint using iron and cobalt ellipsoids.

86. E. Lopuchin, *Phys. Zeits. d. Sowjetunion*, v. 5, No. 1, 1934, p. 57–74. Presents experimental results on the effect on the magnetization of rods when stretched in the earth's field.

87. M. N. Michejew, *Phys. Zeits. d. Sowjetunion*, v. 3, No. 4, 1933, p. 393–8. Investigates the influence of elastic extension of ferromagnetic material at the Curie point, using a nickel-copper alloy.

88. J. M. Ide, I.R.E. *Proc.*, v. 22, 1934, p. 177–90. Studies of a considerable number of ferromagnetic alloys of iron, nickel, chromium and cobalt, with respect to their action as magnetostrictive oscillators.

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91. W. Schutz, *Zeits. f. Physik*, v. 78, No. 9–10, 1932, p. 697–703. (Same subject as reference 90.)

92. R. Becker and M. Kornetzki, *Zeits. f. Physik*, v. 88, No. 9–10, 1934, p. 634–46. Offer experimental results and a theoretical discussion of torsional magneto-elastic effects.

93. K. Aoyagi, *Jl.* I.E.E., Japan, v. 53, 1933, p. 654–66. Discusses the magnetostrictive constants and motional impedances of magnetostrictive resonators.

94. F. Bitter, *Phys. Rev.*, v. 42, 1932, p. 697–708. Gives a theoretical discussion of the properties of homogeneously distorted cubic ferromagnetic lattices.

95. W. Fricke, *Zeits. f. Physik*, v. 80, No. 5–6, 1933, p. 324–41. Presents a new experimental method of determining the change of cross section of a cylindrica rod of ferromagnetic material subjected to a magnetic field parallel to its length. Measurements were made on iron, nickel, and cobalt.

96. S. R. Williams, Am. Soc. for Steel Treating *Trans.*, v. 21, 1933, p. 741–68. Presents an extensive study of the relation between magnetostriction and mechanical hardness, and also shows that the magnetizing process produces changes in hardness.

IX—Magnetic Fields

97. M. Landolt, Assn. Suisse Elec. *Bul.*, v. 24, 1933, p. 357–9. Discusses the new electrical and magnetic units with reference to magnetic field equations.

98. F. K. Harris, Bureau of Standards *Jl. of Research*, v. 13, 1934, p. 391–410. Describes coil arrangements for producing uniform magnetic fields throughout a long cylindrical volume.

99. I. I. Rabi, *Rev. Sci. Instruments*, v. 5, 1934, p. 78–9. Gives a theory covering 2 methods of producing a uniform magnetic field.

100. G. Fanselau, *Terr. Mag.*, v. 38, 1933, p. 277–82. Presents tables for use in terrestrial magnetic field measurements.

X—Effect of Heat Treatment

101. G. A. Kelsall, *Physics*, v. 5, 1934, p. 169–72. Presents data on permeability changes in ferromagnetic materials heat treated in magnetic fields. Permeabilities of over 140,000 have been obtained for "permalloy" by such a treatment.

102. I. N. Zavarine, A.I.M.E. *Trans.*, v. 113, 1934, p. 190–201. Gives data on the magnetic transformations in carbon steels during quenching.

XI—Effect of Temperature

103. P. Weiss, *Comptes Rendus*, v. 198, 1934, p. 1893–5. Presents data on values of magnetic saturation at very low temperatures, lowest values being at 20 degrees Kelvin.

104. P. S. Epstein, Nat. Acad. Sci. *Proc.*, v. 19, 1933, p. 1044–52. Gives a theoretical discussion of the effect of temperature on magnetic saturation of single crystals.

105. J. Seigle; *Jl. de Physique et le Radium*, v. 5, 1934, p. 37–48. Considers the magnetic changes in iron and steel as a function of temperature. The data are correlated with dimension changes and constitutional structure.

106. H. H. Potter, Roy. Soc. *Proc.*, v. 146, 1934, p. 362–87. Describes theoretical and experimental work on the magnetic properties of nickel and iron near the Curie point.

107. T. Kahan, *Comptes Rendus*, v. 199, 1934, p. 349–51. Discusses the effect of variation of temperature on the demagnetization factor of specimens of nickel and cobalt cylinders.

XII—Barkhausen Effect

108. H. Brion, *Ann. d. Physik*, v. 15, No. 2, 1932, p. 167–97. Gives a theoretical discussion of the relation between the Barkhausen effect and rotational hysteresis and magnetization.

109. C. W. Heaps, *Phys. Rev.*, v. 45, 1934, p. 320–3. Deals with experimental results on discontinuities of resistance associated with the Barkhausen effect, his specimens being a nickel wire under bending stress.

110. R. E. Reinhart, *Phys. Rev.*, v. 45, 1934, p. 420–4; and v. 46, p. 483–6. Has investigated large Barkhausen discontinuities and their propagation in nickel-iron alloys under conditions of circular field, longitudinal field, torsion, and tension.

111. K. J. Sixtus and L. Tonks, part I, *Phys. Rev.*, v. 37, 1931, p. 930–58; part II, v. 42, 1932, p. 419–35; part III, v. 43, 1933, p. 70–80; part IV, v. 43,

1933, p. 931–40; and v. 39, 1932, p. 357–8 and 375–6. Have written a series of papers dealing with the propagation of large Barkhausen discontinuities.

112. F. Hulster, *Zeits. f. techn. Physik*, v. 13, No. 11, 1932, p. 516–31; and v. 13, No. 12, p. 618. Has 2 papers dealing with large magnetic discontinuities of the Barkhausen type.

113. F. J. Beck and L. W. McKeehan, *Phys. Rev.*, v. 42, 1932, p. 714–20. Give experimental data on the Barkhausen effect in rotating fields for single crystal disks of silicon steel.

114. O. Tesche, *Phys. Zeits*, v. 34, 1933, p. 879. Gives experimental data on the Barkausen effect below and above the Curie point for samples of iron, nickel, and cobalt, and various kinds of steel.

XIII—Commercial Magnetic Materials

115. R. F. Edgar, A.I.E.E. Trans., v. 52, Sept.-Dec. 1933, p. 721–5; disc. 725–6; and Elec. Engg., v. 53, Feb. 1934, p. 318–22. Describes methods of testing and gives experimental data on the loss characteristics of silicon steel with combined a-c and d-c excitation.

116. S. Procopiu, *Comptes Rendus*, v. 196, 1933, p. 1976–9. Gives an expression for the magnetization and susceptibility of iron under the condition of a superposed a-c field on a constant field.

117. S. S. Sidhu, *Indian Jl. Phys.*, v. 8, 1934, p. 451–67. Develops new formulas for the hystersis loss with superposed direct-current for commercial silicon steel and nickel-iron alloys. These are derived from experimental data.

118. Edel-Agatha Neumann, *Zeits. f. Physik*, v. 83, No. 9–10, 1933, p. 619–31. Discusses the existence of so-called "after effect" in the hysteresis loop at high inductions developing from a-c magnetization.

119. H. Neumann, *Wiss. Veroff. a. d. Siemens-Konzern*, v. 13, No. 3, 1934, p. 10–30. Gives a method of obtaining constant maximum permeability in a magnetic circuit by mixing different magnetic materials.

120. M. Kersten, *Zeits. f. techn. Physik*, v. 15, No. 7, 1934, p. 249–57. Discusses new magnetic powder materials called "isoperms."

121. O. Dahl and J. Pfaffenberger, *Zeits. f. techn. Physik*, v. 15, No. 3, 1934, p. 99–106. Compare the magnetic properties of "isoperms" with soft iron and nickel-iron alloys, with reference to their use in telegraphy.

122. O. Dahl and J. Pfaffenberg, *Zeits. f. Metallkunde*, v. 25, 1933, p. 241–4; disc. p. 245. Discusses the properties and effect of different alloying elements on "perminvars" and "permalloys."

123. W. Arkadiew, *E.N.T.*, v. 10, 1933, p. 220–2. Gives a mathematical treatment dealing with curves and calculations of permeability and hysteresis loss in thin laminas.

124. W. Arkadiew, *Phys. Zeits. d. Sowjetunion*, v. 3, No. 1, 1933, p. 1–28. Gives formulas and curves for the calculation of the permeability and hysteresis loss in ferromagnetic laminas for various frequencies.

125. M. Kersten, *Wiss. Veroff. a. d. Siemens-Konzern*, v. 13, No. 3, 1934, p. 1–9. Discusses the effect of copper on the shape of the magnetization curve of cold-rolled iron-nickel-copper alloys.

126. B. Hague, *E.u.M.*, v. 51, 1933, p. 208–11. Discusses the magnetic properties of "hipernik," "permalloy," and "mumetal," and their application to modern current transformers.

127. F. Stablein, *Zeits. f. techn. Physik*, v. 13, No. 11, 1932, p. 532–4. Describes apparatus and gives experimental results on the measurement of the coercive force of iron-nickel alloys and data on the effect of the addition of silicon.

128. K. W. Grigorow, *Phys. Zeits. d. Sowjetunion*, v. 3, No. 4, 1933, p. 418–20. Offers data on magnetic properties of electrolytically deposited films of iron and the effect of heat treatment on these properties.

129. W. E. Ruder, Am. Soc. for Metals *Trans.*, v. 22, 1934, p. 1120–31. Discusses the influence of grain size on magnetic properties and includes some data on the hysteresis loss in single crystals and the effect of grain orientation on magnetic properties.

130. New development in Electrical Strip Steels Characterized by Fine Grain Structure Approaching the Properties of Single Crystals, N. P. Goss. *Advance Paper No. 30*, presented at the October 1–5, 1934 meeting of the American Society for Metals. Announces a new magnetic sheet having exceptionally good magnetic properties in the direction parallel to rolling.

XIV—Permanent Magnet Materials

131. K. Honda, H. Masumoto, and Y. Shirakawa, Tohoku Univ. *Sci. Reports*, v. 23, 1934, p. 365–73. In English, *Report No. 325* of the Res. Inst. for Iron, Steel and Other Metals. Give a summary of the composition and magnetic properties of recently developed permanent magnet steels, including data on a new steel having very high coercive force and called "new K. S. magnet steel."

132. *A.T.M.*, v. 3, T. 56, 1934. A discussion is given of the properties of Mishima permanent magnet steel (a Ni-Al-Fe alloy) as compared with the older, better known permanent magnet steels.

133. W. Elenbaas, *Zeits. f. techn. Physik*, v. 14, No. 5, 1933, p. 191–7. Develops formulas and methods of designing permanent magnets.

134. R. L. Dowdell, Am. Soc. for Metals *Trans.*, v. 22, 1934, p. 19–30. Presents an investigation of the treatment of steel for permanent magnets.

XV—Lifting Magnets

135. E. Jasse, *E.u.M.*, v. 50, 1932, p. 617–20. Describes an analytical investigation of lifting magnets, neglecting leakage.

136. E. Jasse, *E.u.M.*, v. 51, 1933, p. 8–10. Describes an analytical investigation of lifting magnets including leakage.

XVI—High Frequency Magnetic Properties

137. K. Kreielsheimer, *Ann. d. Physik*, v. 17, No. 3, 1933, p. 293–332. Gives data on the magnetic permeability of iron wires in the wave length region of 46 to 1,000 meters for H values from 0 to 12 oersteds, using a bridge method.

138. W. Arkadiew, *Zeits. f. Physik*, v. 79, No. 7–8, 1932, p. 558–61. Reviews the results of a number of investigations on the anomalous behavior of permeability at high frequencies.

139. J. B. Hoag and H. Jones, *Phys. Rev.*, v. 42, 1932, p. 571–6. Present data on the initial permeability of iron at ultra high radio frequencies. From 64 to 22 centimeter wave lengths, there is shown a decreasing effective initial permeability with decreasing wave lengths.

140. J. Müller, *Zeits. f. Physik*, v. 88, No. 3–4, 1934, p. 143–60. Describes a thermal method of measuring the high frequency resistance of wires and gives permeability data for wave lengths between 4 and 10 meters.

141. R. Sanger, *Helv. Phys. Acta*, v. 7, No. 5, 1934, p. 478–80. Discusses the dependence of permeability of iron, nickel, and cobalt wires on frequency, showing a decrease of permeability at very high frequencies of the order of 10 to 100 centimeter wave lengths.

142. F. M. Colebrook, Dept. Sci. and Indus. Res. Pub., *Special Report No. 14*, 1934. Gives a very complete survey of commercial materials for use at radio frequencies, and includes a very good bibliography.

143. P. K. Taylor, I.R.E. *Proc.*, v. 22, 1934, p. 886–96. Discusses the action of high frequency a-c magnetic fields on suspended magnetic rings and offers a method of measuring the intensity of high frequency magnetic fields as a function of torque.

XVII—Magnetic Skin Effect

144. E. Hinze, *Ann. d. Physik*, v. 19, No. 2, 1934, p. 143–54. Considers the theory of skin effect in ferromagnetic circular cylinders under the influence of weak alternating fields, dealing with both permeability and hysteresis losses.

XVIII—Magnetic Oxides

145. L. A. Welo and O. Baudisch, *Phil. Mag.*, v. 17, 1934, p. 753–68. Discuss the ferromagnetism in gamma ferric oxide and include some data on the effect of temperature.

146. H. Forestier and G. Guiot-Guillain, *Comptes Rendus*, v. 199, 1934, p. 720–3. Give data on the magnetic properties of various ferric oxides including the effect of heating at various temperatures and for different lengths of time.

XIX—Heusler Alloys

147. O. Heusler, *Zeits. f. Metallkunde*, v. 25, 1933, p. 274–7; disc. p. 277–8. Deals with the crystal structure and ferromagnetism of Mn-Al-Cu alloys.

148. O. Heusler, *Ann. d. Physik*, v. 19, No. 2, 1934, p. 155–201. Deals with the crystal structure and ferromagnetism of Mn-Al-Cu alloys, including the magnetic characteristics considered as a function of heat treatment, temperature, composition, and field strength.

149. A. J. Bradley and J. W. Rodgers, Roy. Soc. *Proc.*, v. 144, 1934, p. 340–59. Present a study of the ferromagnetic properties of Heusler alloys as a function of structure for a given chemical composition.

150. S. Valentiner and G. Becker, *Zeits. f. Physik*, v. 83, No. 5–6, 1933, p. 371–403. Present studies of the magnetic properties of Heusler alloys as a function of composition, temperature, and aging treatment.

XX—Magnetic Properties of Minerals

151. J. G. Koenigsberger, *Beitr. z. angew. Geophys.*, v. 4, No. 3, 1934, p. 385–94. Discusses the remanent magnetism of ferromagnetic minerals as a function of geologic age.

152. G. Grenet, *Comptes Rendus*, v. 197, 1933, p. 874–5. Describes an apparatus for measuring the magnetic properties of rocks.

153. G. Grenet, *Comptes Rendus*, v. 197, 1933, p. 746–8. Discusses the theory of ferromagnetic powders and the magnetic susceptibility of rocks.

XXI—Magnetic Properties of Thin Films

154. S. Procopiu and T. Farcas, *Comptes Rendus*, v. 198, 1934, p. 1983–5. Give experimental results and a theoretical discussion of the Curie point as a function of the thickness of electrolytically deposited nickel films with an explanation of the possible cause of variations.

155. S. Procopiu, *Jl. de Physique et le Radium*, v. 5, 1934, p. 199–206. Deals with coercive force values of thin films of iron with superposed a-c field, considering the effect of frequency and gives formulas for the phenomenon.

156. K. Richter, *Kolloid Zeits.*, v. 61, 1932, p. 208–18. Discusses the electrical conductivity and other physical properties of thin metallic films as well as magnetic properties.

XXII—Magnetic Aging

157. An Example of Magnetic Aging, J. Muir. *Jl.* of the Royal Tech. College (Glasgow), v. 3, part 2, January 1934. Gives experimental data on the permeability aging of soft steel at fairly high magnetizing forces.

XXIII—Magnetic Properties in Weak Fields

158. H. Wittke, *Ann. d. Physik*, v. 18, No. 6, 1933, p. 679–700. Gives experimental results and a discussion of strongly reversible phenomena in the magnetization of ferromagnetic bodies in very low alternating fields.

159. H. Wittke, *Ann. d. Physik*, v. 20, No. 1, 1934, p. 106–12. Presents further experimental results on quasistatic magnetic cycles in weak fields, explaining the results as being due to magnetic "after effect."

XXIV—Magnetic Testing of Materials

160. E. Thellier, *Comptes Rendus*, v. 197, 1933, p. 232–4. Describes a double astatic magnetometer.

161. H. N. Otis, *Rev. Sci. Instruments*, v. 4, 1933, p. 681–3. Describes a torsion magnetometer for testing thin ferromagnetic specimens.

162. L. W. McKeehan, *Rev. Sci. Instruments*, v. 5, 1934, p. 265–8. Describes a modification of the pendulum magnetometer making it suitable for the study of small ferromagnetic specimens.

163. J. Sugiura, Electrotech. Lab., Tokyo, Japan, *Research No. 354*, 1933. Describes a new permeameter claimed to have high accuracy, designed particularly for use with high magnetizing forces.

164. R. L. Sanford and E. G. Bennett, Bureau of Standards *Jl. of Research*, v. 10, 1933, p. 567–73. Describe a new apparatus for general magnetic testing at high magnetizing forces from 100 to 1,000 oersteds. The apparatus does not heat the specimen.

165. P. C. Hermann, *Zeits. f. techn. Physik*, v. 14, No. 1, 1933, p. 39–44. Describes a new method for making magnetic measurements on thin disks of metal. Comparisons are made with other methods of test.

166. P. C. Hermann, *Zeits. f. techn. Physik*, v. 13, No. 11, 1932, p. 541–9. Discusses a new apparatus for making magnetic tests on thin strips of material using both direct and alternating current.

167. C. Dannatt, *Jl. Sci. Instruments*, v. 10, 1933, p. 276–85. Describes a new method of making magnetic loss tests on single strip specimens. Discusses the errors due to harmonics.

168. H. Kühlewein, *Zeits. f. techn. Physik*, v. 14, No. 8, 1933, p. 314–16. Gives 2 methods for the investigation of the magnetic properties of high permeability material in the form of laminated rings. By means of the second test, the Curie point may be determined.

169. R. Jouaust, Soc. Franc. Elec. *Bul.*, v. 3, 1933, p. 885–90. Discusses the accuracy of the Epstein method of measuring core losses.

170. B. R. Isaacs, *Electrician*, v. 109, 1932, p. 679–81. Describes a method of testing an iron sample magnetically and deals with the construction of the magnetic circuit.

171. G. Keinath, *Physik*, v. 1, No. 1, 1933, p. 21–40. Gives a survey of modern instruments and methods available for magnetic and electrical measurements.

172. B. Hague, Congres Intl. d'Electricite, Paris, Sec. 3, *Rapport No. 7*, 1932. Offers a review of the available methods for measuring the distribution of the magnetic field in electrical machinery and other apparatus.

173. A. P. M. Fleming, *Jl.* I.E.E., London, v. 73, 1933, p. 591–5. Reviews the subject of electrical measurements and their relation to the technical progress of industry, including data on modern methods of testing magnetic materials.

174. W. Thal, *A.T.M.*, v. 3, 1934, T. 78–9. Discusses the accuracy of various methods of determining the magnetic properties of magnetic materials and includes some information on the effect of inhomogeneities on the accuracy of measurement.

175. S. Procopiu and N. Florescu, *Jl. de Physique et le Radium*, v. 4, 1933, p. 251–61. Deal with the demagnetization of iron, steel, and nickel wires of various diameters and for a wide range of frequencies from 50 to 1,000,000 cylces per second.

176. A. W. Smith, *Jl. Sci. Instruments*, v. 3, 1932, p. 626–31. Discusses a reversing and short-circuiting switch for use in making hysteresis measurements.

177. R. P. Johnson and W. B. Nottingham, *Rev. Sci. Instruments*, v. 5, 1934, p. 191–2. Describe a suspension for instruments which provides a constant level and protection from small vibrations.

178. H. Neumann, *A.T.M.*, v. 3, 1934, T. 67–8. Discusses a number of methods of measuring magnetic potential by means of search coils.

179. J. L. Snoek, *Physica*, v. 1, 1934, p. 649–54. Calculates the demagnetization factors for thin cylinders of small dimension ratio and checks the calculations by test.

180. E. A. Neumann and J. Pfaffenberger, *Arch. f. Elektrotech.*, v. 27, 1933, p. 287–94. Discuss a method of making iron loss measurements on small ring samples using a synchronous rectifier and meter for flux measurements and a wattmeter for determining the losses. This method makes possible the use of small samples.

181. M. Knoll and W. Kleen, *A.T.M.*, v. 3, 1934, T. 14. Describe a method of obtaining hysteresis cycles by means of the cathode ray oscillograph.

182. P. Bricout and R. Salomon, *Comptes Rendus*, v. 199, 1934, p. 529–31. Describe the use of the cathode ray oscillograph for a study of the magnetization of ferromagnetic substances primarily for the purpose of detecting differences in steels of the same composition with slightly different heat treatments.

183. O. v. Auwers, *Zeits. f. techn. Physik*, v. 14, No. 8, 1933, p. 316–19. Describes a photographic method for recording magnetic flux changes using a special type of galvanometer.

184. W. B. Ellwood, *Rev. Sci. Instruments*, v. 5, 1934, p. 300–5. Describes a resonance ballistic galvanometer of very high sensitivity operated in a vacuum for use in magnetic flux measurements.

185. E. W. Golding, *Electrician*, v. 111, 1933, p. 503–5. Discusses the Grassot fluxmeter and its advantages over the ballistic galvanometer for magnetic measurements.

XXV—Magnetic Fields—Determination of Strength

186. H. Auer, *Ann. d. Physik*, v. 18, No. 6, 1933, p. 613–25. Describes an absolute method of making magnetic field measurements.

187. H. Buchner, *Phys. Zeits.*, v. 35, 1934, p. 409–10. Describes a method of measuring the magnetic field strengths using a small aluminum cylinder controlled by a spring.

188. H. S. Jones, *Rev. Sci. Instruments*, v. 5, 1934, p. 211–14. Discusses a method of measuring the intensity of magnetic fields by means of a small spring-suspended coil, carrying a variable current which is a measure of the field strength.

189. S. E. Forbush, *Terr. Mag.*, v. 39, 1934, p. 135–43. Discusses devices for measuring the changes in the horizontal intensity of the earth's magnetic field.

190. L. F. Bates, Phys. Soc. *Proc.*, v. 45, 1933, p. 180–92; disc. p. 193. Describes a new method for measuring the vertical and horizontal components of the earth's magnetic field using a "mumetal" cylinder carrying a fine wire winding.

XXVI—Magnetic Anisotropy

191. A. Schigadlo and S. Sidelnikov, *Phys. Zeits. d. Sowjetunion*, v. 5, No. 5, 1934, p. 714–21. Consider the crystal orientation of cold-worked material and calculate the hysteresis loss as compared with test results.

192. A. Drigo, *N. Cimento*, v. 11, 1934, p. 345–56. Studied the variation in permeability of disks of magnetic sheet as a function of orientation.

XXVII—Low Induction Magnetic "After Effects"

193. E. A. Neumann, *Zeits. f. Physik*, v. 89, No. 5–6, 1934, p. 308–16. Discusses reversible magnetic processes and magnetic "after effect."

194. R. Goldschmidt, *Zeits. f. techn. Physik*, v. 13, No. 11, 1932, p. 534–9. Discusses the magnetic "after effect" in weak alternating fields.

195. P. C. Hermann, *Zeits. f. Physik*, v. 84, No. 9–10, 1933, p. 565–70. Discusses the subject of magnetic "after effect."

196. R. L. Sanford, Bureau of Standards *Jl. of Research*, v. 13, 1934, p. 371–6. Gives data on the magnetic drift at low inductions after demagnetization, showing that these changes may amount to a considerable percentage.

XXVIII—Magnetic Viscosity

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XXX—Magnetic Noise

204. S. J. Mikina, A.S.M.E. *Trans.*, v. 56, 1934, p. 711–20. Describes the various modes of vibration of rotating machine frames resulting in magnetic noise and considers methods of reducing these effects.

XXXI—Miscellaneous

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209. A. Kussmann, *Zeits. f. Metallkunde*, v. 26, 1934, p. 25–33. (Same subject as reference 208, but covering ferromagnetic material.)

210. L. Slepian, *Phys. Zeits. d. Sowjetunion*, v. 3, No. 5, 1933, p. 469–86. Discusses from experimental and theoretical standpoints the subject of unipolar induction.

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Self Excitation of a Frequency Converter

After a general discussion of the phenomenon of self excitation of a-c machines, a specific case of 3 phase self excitation of a Scherbius machine is treated. Such a machine is used in the regulating set of a variable-ratio frequency converter for inherently constant power transfer, the operating features of which are described. Under certain conditions this converter may be subject to the danger of self excitation. These conditions are discussed in detail and means are indicated to prevent self excitation during the normal operation of this converter.

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THE object of this paper is a discussion of the probability and the danger of self excitation of a Scherbius 3 phase commutator machine as employed in a variable-ratio frequency converter, with inherently constant power transfer. This and other types of variable-ratio frequency converters are used as a tie between 2 power systems whenever the power transfer has to be independent of the frequencies of the systems. They consist of a synchronous machine connected to one system and an induction machine connected to the other system; a regulating set is used in conjunction with the induction machine. The regulating set ordinarily is composed of a stator or rotor-fed a-c commutator machine together with its exciting and regulating equipment to change the electromotive force of the commutator machine properly in phase and magnitude. Various schemes of using the commutator machine to control the frequency converter are used, but the one to which particular attention is given in this paper is designed so that the power transfer within the operating range is inherently constant, a Scherbius machine being used for control.

The principal conclusions which may be drawn as a result of the study presented in this paper are as follows:

1. The Scherbius machine used in a variable-ratio frequency converter for inherently constant power transfer as proposed by Seiz may be subject to 3 phase self excitation.

2. Because of the relatively low self-excited rotor frequency and the correspondingly high rotor currents self excitation must be prevented.

3. The danger of self excitation decreases among other things with a reduction of the induced electromotive forces in the field circuits of the exciter of the Scherbius machine, increasing short-circuiting effect of the network, increasing ohmic component of the load impedance, and increasing leakage inductance of the Scherbius machine.

4. A self-excited field in the Scherbius machine may, in principle, rotate in either direction. There are, however, usually external conditions which cause 1 of the 2 to be preferred.

5. If the frequency changer ampere turns are relatively high, the sense of rotation is primarily determined by the direction of power flow during normal operation. The sense is such that the frequency ampere turns have a component in phase with the slip ring ampere turns.

6. If the frequency changer ampere turns are small, the field rotates in such a direction that the rotor of the induction machine covers part of the losses of the rotor circuit. This is dependent upon the self-excited stator frequency being below the network frequency. Self excitation will, therefor, preferably be supersynchronous (sense of rotation of rotor field during self excitation equal to that during normal supersynchronous operation).

7. The self-excited Scherbius machine may operate as a generator or as a motor if it only provides the magnetizing power for the self-excited circuits. The larger part of the active power during self excitation is drawn from or delivered to the shaft of the induction machine. The remainder is supplied or absorbed by the network and the Scherbius machine.

The various phases of the problem for self excitation of a frequency converter for inherently con-

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stant power transfer will be treated in this paper in the following order:

1. Self excitation of commutator, particularly Scherbius, machines.
2. A variable-ratio frequency converter with inherently constant power transfer.
3. The problem of self excitation of this converter.

Self Excitation of Commutator Machines in General

An electric machine is called self excited if a voltage, assumed to exist across its terminals, supplies to its field circuits a magnetizing power sufficient to maintain this voltage. If the field does not vary with time, the magnetizing power is equal to the ohmic losses of the field circuits. An example of such a machine is the self-excited d-c generator. Should it be desired, however, that self excitation occur with alternating current, both the active and the reactive magnetizing power have to be supplied by the self-excited machine. As the reactive power causes the field current to lag behind its supply voltage, means have to be provided to compensate this phase difference. Unless this is done, a-c self excitation will not occur. Thus, a-c self excitation of the normal d-c generator is impossible because a given terminal voltage would not produce a current of the proper phase to sustain this voltage. Only by inserting into the field circuit capacitance great enough to compensate the inductive voltage drop at a given frequency could a-c self excitation be rendered possible. (For reasons not directly connected with this such a machine would have to be built with laminated iron and a compensating winding in the stator.) This is an obvious result if it is remembered that a-c self excitation is equivalent to the generation of undamped oscillations. Without the help of capacitance or its equivalent, the field of a single phase commutator machine running at constant speed could not periodically lose and regain its energy because no other energy store for the magnetic energy is available.

In the case of a 2-phase or 3-phase commutator machine, a-c self excitation is not dependent upon capacitance. Ruedenberg[1] has shown that the oscillations of a self-excited 3-phase shunt commutator machine consist of a periodic transfer of the magnetic energy from one phase to another. A similar example is the self-excited Scherbius machine, as described by Hull,[2] to which reference will be made later in this paper.

Once the conditions for self excitation are satisfied, it usually starts due to some impulse, *e. g.*, electrical or mechanical transients or residual magnetism. Voltage and current will then rise until the saturation of the magnetic paths prevents a further increase. For this reason self excitation is undesirable, often even very dangerous whenever a machine is not primarily intended to be a self-excited generator.

Self Excitation of a Scherbius Machine

After this general discussion the conditions for self excitation of a Scherbius machine will be treated. This will be preceded by a short description of the machine itself.

The stator of the Scherbius machine has salient main poles, 120 electrical degrees apart, with auxiliary poles in between. In addition it is provided with a compensating winding to counteract exactly the ampere turns of the rotor winding. Its rotor resembles that of a d-c machine, but differs from it by a winding pitch and a distance between brushes of 120 instead of 180 electrical degrees. The rotor electromotive force is induced by rotation only.

In his paper on a self-excited Scherbius machine Hull[2] has shown that such a machine is capable of

Fig. 1. Three phase diagrams of a Scherbius machine

a—Three phase diagrams of electromotive force (flux), field current, and ampere turns

b—Schematic circuit diagram of a shunt excited Scherbius machine during 3 phase self excitation

c—Three phase diagrams of field and load currents and ampere turns of a shunt-excited counter-compounded and inductively loaded Scherbius machine during 3 phase self excitation

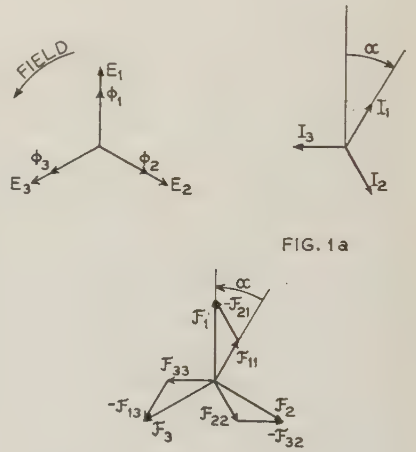


FIG. 1a

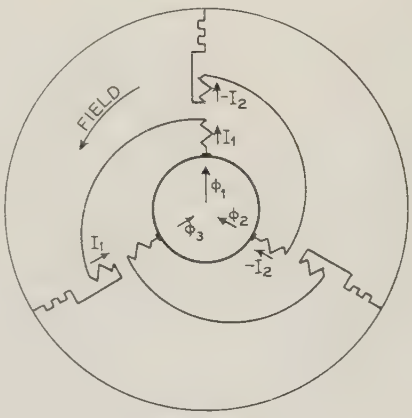


FIG. 1b

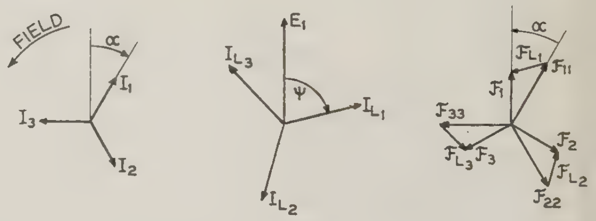


FIG. 1c

1. For all numbered references, see list at end of paper.

operating as a self-excited 3-phase generator if, besides a sufficiently low field resistance, the ampere turns of a given pole *lead* the field current, flowing through the brushes under this pole, by the same angle α by which this field current *lags* the electromotive force induced under this pole. Expressed in other words the lagging in time of the field current has to be compensated by a leading in space of the axis of the field windings. By these means a self-excited field in the Scherbius machine is forced to rotate in space. As an illustration figure 1*a* shows the 3 phase diagrams of flux ϕ, electromotive force E, field current I and ampere turns $\mathfrak{F}$ of a self-excited Scherbius machine. Figure 1*b* gives a schematic diagram of its rotor and field circuits and the magnitude of flux and field currents for the instance when the flux through pole 1 is at its maximum. The above-mentioned phase angle α is assumed to be 30 degrees. In order to bring the total ampere turns of pole 1 in phase with the flux ϕ_1, it is necessary to excite pole 1 not only by the field current I_1 (I_1 and ampere turns $\mathfrak{F}_{11}$ *lagging* $\boldsymbol{E}_1$ and ϕ_1 by 30 degrees) but also by current I_2 producing the ampere turns $-\mathfrak{F}_{21}$. If the number of turns of these 2 windings is equal, $\mathfrak{F}_1$ will *lead* $\mathfrak{F}_{11}$ by 30 degrees, i. e., $\mathfrak{F}_1$ and ϕ_1 are in phase.

If the angle α is reduced to zero, i. e., each pole is excited only by a field current flowing through brushes under this pole, only d-c self excitation is possible because for no other but zero frequency could I_1 and E_1, i. e., $\mathfrak{F}_{11}$ and ϕ_1 be in phase. It is, however, obvious that even with only one shunt winding per pole, 3 phase self excitation is possible as long as another current of the proper frequency and phase flows through a second winding on this pole. If it should be sufficient that self excitation occurs only under load, it is always possible to send the load current through a proper compound or anticompound winding and compensate for the lagging of the ampere turns $\mathfrak{F}_{11}$. As an example of such an arrangement figure 1*c* shows the 3 phase diagrams of the field currents I, inductive load currents I_L and ampere-turns $\mathfrak{F}$ of the Scherbius machine if each pole is excited only by currents flowing through the brushes under this particular pole. As will be seen later, these are the fundamental conditions of self excitation of the Scherbius machine as used in a frequency converter to be described.

It is of interest to conclude from figure 1*c* that for a given compound winding self excitation is only possible if the phase angle between the load current and the electromotive force of the Scherbius machine remains within a certain range. Outside of this range self excitation cannot occur. For instance, for an inductive load it is only possible with an anticompound winding.

A Variable-Ratio Frequency Converter With Inherently Constant Power Transfer

Before describing the principle and the main operating features of this converter (the possibility of self excitation of which will be discussed later in this paper) a short account of variable ratio frequency converters in general will be given. They are used as a flexible tie between 2 power systems to transfer—within the operating range of the converter—an arbitrary, often constant amount of power independently of the frequencies of the 2 systems.

The converters consist of a synchronous machine connected to one system and an induction machine with its regulating set connected to the other system. With few exceptions the regulating set is composed of a stator or rotor-fed a-c commutator machine and its exciting and regulating equipment.

The commutator machine introduces into the rotor circuit of the induction machine an electromotive force which together with its rotor electromotive force covers the voltage drop of the desired rotor current. By properly changing the electromotive force of the commutator machine any rotor current for any slip—within the operating range of the set—can be obtained.

The manner, now, in which this electromotive force is changed with varying slip, i. e., in which the field of the commutator machine is controlled gives rise to a large variety of connection diagrams of variable ratio frequency converters. Two main groups may be distinguished. In the first group the field is controlled by an automatic load regulator, which changes the field voltage of the main commutator machine in magnitude and phase, *e. g.*, by varying independently the currents through 2 field windings, perpendicular to each other, of a small synchronous machine or by shifting the brushes of a frequency changer, also called ohmic drop exciter. (The frequency changer consists of a d-c rotor revolving inside of a closed magnetic path with slip rings tapped to the armature and connected to the 3 phase supply. On the commutator slide sets of brushes, *e. g.*, 2, the brushes of each set being 120 degrees apart. The desired voltage is obtained by shifting the 2 sets against each other and jointly with respect to the frame of the machine.) This type of control is in exclusive use in the United States and has been described in several papers.[3,4,5,6]

The excitation of the commutator machine in the second group is designed in such a way that the power transfer within the operating range is inherently constant. The first converter of this kind, with a Scherbius machine as the main commutator machine, is due to Seiz.[7,8] The principle, however, is not restricted to stator fed machines and even for these a variety of circuit diagrams has been proposed.[9,10,11]

The basic idea of the Seiz circuit is to neutralize completely the slip ring voltage of the induction machine for any operating slip by one electromotive force component of the commutator machine, i. e., to prevent any rotor current from flowing and then, by a second component, to introduce the necessary voltage for the desired rotor current.

A typical circuit diagram of this converter is shown in figure 2. In this figure, 1 and 2 are the synchronous and induction machines connected to their respective systems; 3 the commutator machine, and 4 the frequency changer with its transformer 5; 6 and 7 are resistances; and 8 an exciter driven by the motor 9. This exciter is a small Scherbius machine with a powerful counter-compound winding of such a magnitude that the resultant ampere turns of the

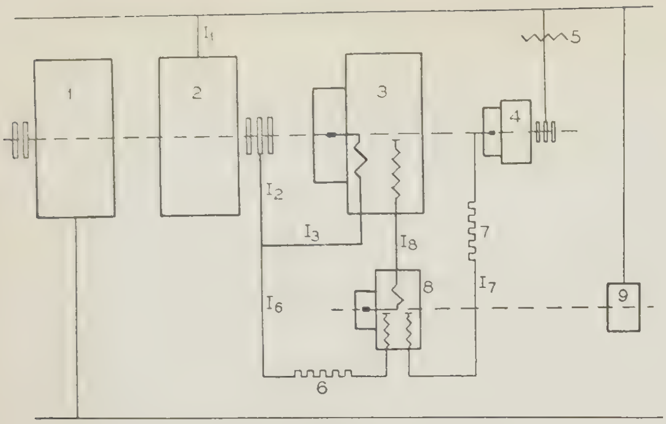


Fig. 2. Connection diagram of a frequency converter for constant power with exciter

1—Synchronous machine
2—Induction machine
3—Commutator machine
4—Frequency changer
5—Auxiliary transformer
6—Resistance in the slip ring excitation circuit
7—Resistance in the frequency changer excitation circuit
8—Exciter
9—Motor of the exciter

I_1—Stator current of the induction machine
I_2—Rotor current of the induction machine
I_3—Armature current of the commutator machine
I_6—Slip ring excitation current
I_7—Frequency changer excitation current
I_8—Field current of the commutator machine

exciter are only a fraction of the anti-compound and field ampere turns. It acts as current amplifier and serves the reduction of the field losses, but is not essential for the understanding of the operation of the converter.

The 2 electromotive force components of the commutator machine mentioned above are produced by the field circuits shown in figure 2 as resistances 6 and 7. Both circuits are essentially ohmic. The currents in the resistances and the corresponding rotational voltages of the commutator machine are therefore approximately proportional to and in phase with the exciting voltages, i. e., the slip ring and frequency changer voltage, respectively. The first electromotive force component of the commutator machine, neutralizing the slip ring voltage of the induction machine, is produced by the circuit connected to these slip rings (slip ring circuit). The other component is proportional to the current in the circuit connected to the frequency changer (frequency changer circuit). In order to make the rotor current essentially independent of secondary influences, like brush drop, speed, and slight saturation of the commutator machine or leakage reactances in the rotor circuit, the commutator machine has a counter-compound winding.

The power transfer of the converter is changed by known methods, *e. g.*, shifting of the brushes of the frequency changer. For a given position of these brushes the power transfer of the converter is completely defined.

In order to facilitate the later discussion, the voltage, current, and ampere turns diagrams of the converter are given in figure 3 for subsynchronous generator operation of the induction machine. The rotation of the field in these diagrams is counterclockwise, the ratio of the number of turns of the stator and rotor windings is unity, all reactances are calculated for the primary frequency f_1 and iron losses are neglected: the stator electromotive force $\boldsymbol{E}_1$ (figure 3*a*), lagging the flux ϕ by 90 degrees, minus the voltage drop $\boldsymbol{I}_1(R_1 + jX_1)$ gives the primary terminal voltage $\boldsymbol{V}_1$. The primary and secondary currents $\boldsymbol{I}_1$ and $\boldsymbol{I}_2$ (figure 3*b*) result in the magnetizing current I_0, assumed to be in phase with the flux ϕ. In figure 3*c* the rotor electromotive force $\boldsymbol{E}_2 \cdot s$, lagging 90 degrees behind ϕ, minus the voltage drops in the rotor circuits of the induction and commutator machines $\boldsymbol{I}_2\ (R_2 + jX_2 \cdot s) + \boldsymbol{I}_3(R_3 + jX_3 \cdot s)$ plus the voltage $\boldsymbol{E}_{3c}$, induced in the anti-compound winding of the commutator machine, are compensated by its electromotive force $\boldsymbol{E}_3$. (The voltage $\boldsymbol{E}_{3c}$ lags the stray electromotive force $-j\boldsymbol{I}_3X_3 \cdot s$ by the same angle as that by which the resultant ampere turns $\mathfrak{F}_3$ (figure 3*e*) lag the anti-compound ampere turns $\mathfrak{F}_{3c}$. $\boldsymbol{E}_{3c}$ is proportional to the flux of the commutator machine and the rotor frequency f_2, i. e., roughly proportionally to $f_2{}^2$.) In figure 3*d* the current $\boldsymbol{I}_3$ of the commutator machine leads the rotor current $\boldsymbol{I}_2$ because $\boldsymbol{I}_3$ is the sum of the partially inductive current $\boldsymbol{I}_2$ and the essentially ohmic field current $\boldsymbol{I}_6$. The ampere turns $\mathfrak{F}_3$ in figure 3*e* are in phase with $\boldsymbol{E}_3$ (and ϕ_3) and the resultant of the field ampere turns $\mathfrak{F}_4$ and the compound ampere turns $\mathfrak{F}_{3c}$ (in phase opposition to $\boldsymbol{I}_3$).

The remaining diagrams, figures 3*f* to 3*i* refer to the exciter. The electromotive force $\boldsymbol{E}_4$ (figure 3*f*), induced by the flux ϕ_3 in the field winding of the commutator machine and lagging ϕ_3 by 90 degrees, minus the voltage drops in this winding and the exciter $\boldsymbol{I}_8\ (R_4 + jX_4 \cdot s + R_8 + jX_8 \cdot s)$ is equal and opposite to the rotational electromotive force $\boldsymbol{E}_8$ of the exciter. $\boldsymbol{E}_8$, as $\boldsymbol{E}_{3c}$, is roughly proportional to the square of the rotor frequency. (The electromotive force induced in the anti-compound winding of the exciter is neglected.) The ampere turns to produce $\boldsymbol{E}_8$ are $\mathfrak{F}_8$ (figure 3*g*). They are in phase with $\boldsymbol{E}_8$ and the sum of $\mathfrak{F}_6$, $\mathfrak{F}_7$ and $\mathfrak{F}_{8c}$. $\mathfrak{F}_6$ is the ampere turns produced by the field circuit connected to the slip rings of the induction machine (slip ring field) to compensate the slip ring voltage and $\mathfrak{F}_7$ by that connected to the commutator of the frequency changer (frequency changer field) to cause the desired rotor current to flow. $\mathfrak{F}_{8c}$ is the anticompound ampere turns of the exciter; it is almost equal and opposite to the sum of $\mathfrak{F}_6$ and $\mathfrak{F}_7$. (It is of interest to point out that, because of the strong anticompounding of the commutator machine and the exciter, the ampere turns $\mathfrak{F}_6$ and $\mathfrak{F}_7$ of the latter correspond—roughly at least—to the ampere turns $\mathfrak{F}_3$ and $-\mathfrak{F}_{3c}$ of the former.) Figures 3*h* and 3*i* finally give the voltages in the 2 exciter field circuits. They are the simple diagrams of a slightly inductive circuit with the modification that the electromotive forces $\boldsymbol{E}_6$ and $\boldsymbol{E}_7$, induced by the main flux ϕ_8 of the exciter in the respective field windings, lead the negative inductive voltage drops of the field currents $\boldsymbol{I}_6$ and $\boldsymbol{I}_7$ by the same angle as that by which the resultant ampere turns $\mathfrak{F}_8$ lead the ampere turns $\mathfrak{F}_6$ and $\mathfrak{F}_7$. The electromotive forces $\boldsymbol{E}_6$ and $\boldsymbol{E}_7$ are proportional to $E_8 \cdot f_2$,

i. e., they increase roughly with the third power of the rotor frequency.

From these diagrams it may be seen that for direct coupling of the commutator and induction machines and constant primary voltage and frequency there are a number of factors which prevent the rotor current, i. e., the active and reactive power of the induction machine from being entirely independent of the slip. The more important ones are the induced electromotive forces $-j\boldsymbol{I}_2X_2 \cdot s$, $-j\boldsymbol{I}_3X_3 \cdot s$, $\boldsymbol{E}_{3c}$, $\boldsymbol{E}_4 - j\boldsymbol{I}_8(X_4 + X_8) \cdot s$, $\boldsymbol{E}_6 - j\boldsymbol{I}_6X_6 \cdot s$ and $\boldsymbol{E}_7 - j\boldsymbol{I}_7X_7 \cdot s$, the dependence of $\boldsymbol{E}_3$ upon the speed of the commutator machine for constant ϕ_3 and finally the saturation of the commutator machine.

These influences have been discussed in detail in other papers.[8,12] Suffice it here to state that their combined influence (saturation excepted) causes, for subsynchronous speed, the generator power of the induction machine to increase and the motor power to decrease, for supersynchronous speed the generator power to decrease and the motor power to increase and for subsynchronous and supersynchronous speeds the reactive volt-amperes to increase in the sense of overexcitation. In the same papers it was shown that by means of auxiliary circuits it is possible to very considerably reduce or almost compensate the effect of these disturbances. If the auxiliary circuits are omitted and still a close control of the power transfer is demanded, automatic load regulators are required to act as corrective devices.

The Problem of Self Excitation of This Converter

As an introduction a short qualitative account will be given. This is facilitated by 2 facts. First, the exciter 8 in figure 2 is essentially only a current amplifier. Its existence can therefore be neglected. Second, as calculations of typical cases have shown, the self-excited frequency—if self excitation be possible—is usually of such a magnitude that the network of the induction machine is virtually a short circuit for the self-excited voltages. The load of the self-excited Scherbius machine is therefore essentially inductive (as will be seen, roughly, the short circuit impedance of the induction machine and the network) and because of the low self-excited primary voltage of the induction machine, which is also the supply voltage of the frequency changer, the ampere turns produced by the frequency changer circuit may be neglected. The Scherbius machine is thus, as an approximation, inductively loaded, anticompounded and shunt-excited. As it was shown in the first part of this paper that such an arrangement is capable of 3 phase self excitation, it can be concluded that self excitation of the Seiz converter is possible in principle. Whether it actually will occur, depends upon the sum of all available ampere turns being equal or larger than the required ampere turns.

If self excitation does occur, the rotor current of the Scherbius machine will increase to a multiple of its rated current because of the relatively low load impedance. Dependable operation of the converter is therefore only possible if the danger of self excitation during normal operation is definitely eliminated. Means to do this may be derived from an analysis of the different ampere turns contributing to self excitation.

A convenient way of doing so is to retain for the actual converter the picture of a shunt excited, inductively loaded commutator machine. The ampere turns of the commutator machine and the exciter may then be combined and represented for constant flux of the Scherbius machine as components of its resultant ampere turns. As some of these vectors depend upon the load current, it is first necessary to determine the load impedance.

It was already pointed out that the self-excited rotor frequency is usually a multiple of the normal rotor frequency (around 5 to 10 cycles per second). The self-excited stator frequency differs therefore

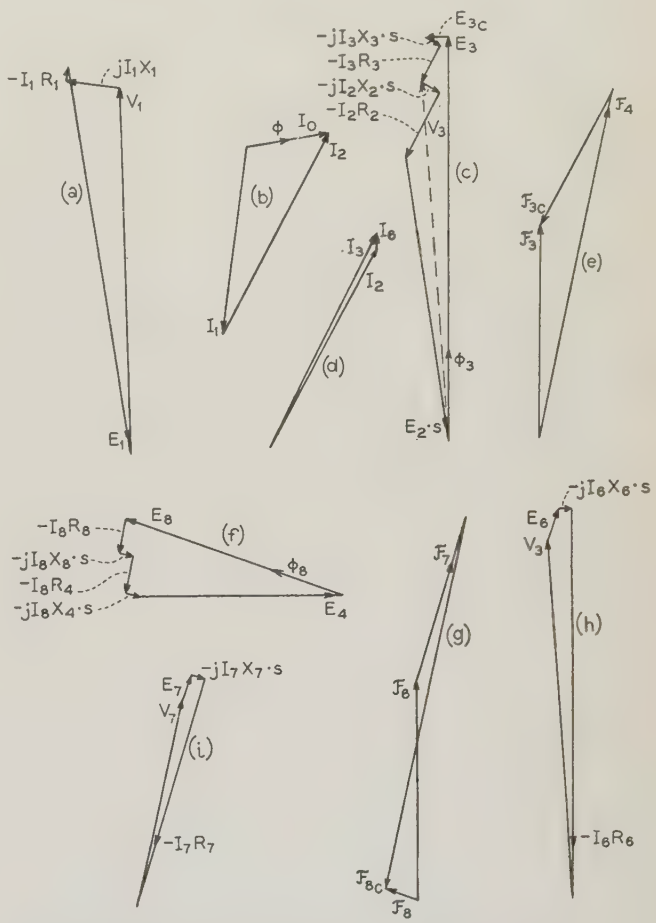


Fig. 3. Voltage, current, and magnetomotive force diagram of a frequency converter for constant power with exciter

a—Voltage diagram of the stator of the induction machine
b—Magnetomotive force diagram of the induction machine
c—Voltage diagram of the rotor circuit of the induction machine
d—Current diagram of the rotor circuit of the induction machine
e—Magnetomotive force diagram of the commutator machine
f—Voltage diagram of the field circuit of the commutator machine
g—Magnetomotive force diagram of the exciter
h—Voltage diagram of the slip ring excitation circuit of the exciter
i—Voltage diagram of the frequency changer excitation circuit of the exciter

enough from the normal stator frequency to make the network act nearly like a short circuit to the self-excited stator voltage. The load of the Scherbius machine is therefore roughly equal to the sum of the short circuit impedances of the induction machine and the network. Their imaginary part can with sufficient accuracy be considered to be proportional to the frequency, i. e., the load inductance is constant. For the real part such a simple relation does not exist; a more detailed discussion is therefore necessary.

A self-excited field in the Scherbius machine may rotate in either direction unless for specific reason one direction is preferred or the only possible one. If the field rotates in the same direction as a field during normal subsynchronous operation of the induction machine (subsynchronous self excitation with positive rotor frequency f_{2s}), the self-excited stator frequency f_{1s} is larger than the normal stator frequency f_1. For negative values of f_{2s}, i. e., supersynchronous self excitation, f_{1s} is smaller than f_1. In the first case all rotating machines connected to the network are running considerably below synchronism with respect to the self-excited stator frequency and act therefore as a motor. In the second case they operate above synchronism and act as a generator.

From these considerations a simple expression for the total load resistance R of the Scherbius machine can be developed by reducing all resistances to the rotor circuit by suitably applying the well-known relation that the secondary resistance R_2 of an induction machine is represented in the primary impedance diagram as $R_2/S = R_2 f_1/f_2$. Thus, as an example, a stator resistance R_1 reduced to the rotor circuit would become $R_1/s' = R_1 \cdot f_2/f_1$. It is further assumed that all rotating machines of the network can be represented by one induction machine (network machine). The load resistance R is then

$$R \approx R_2 + \frac{R_1 + R_{N1}}{s_S} + \frac{R_{N2}}{s_S \cdot s_N} \qquad (1)$$

In this expression R_2 and R_1 are the rotor and stator resistances of the induction machine, R_{N1} the stator resistance of the network machine including possible transmission line resistances and R_{N2} the rotor resistance of the former; $s_s = f_{1s}/f_{2s}$ is the inverse of the slip of the rotor of the induction machine with respect to its self-excited rotational field and $s_N \approx (f_{1s} - f_1)/f_{1s}$ the slip of the network machine—for simplicity assumed to run in synchronism with f_1—with respect to the self-excited stator frequency f_{1s}. As s_s and s_N are positive for subsynchronous self excitation and negative for a supersynchronous one, R is in the first case larger than in the second case. For large values of R_{N1} and negative values of s_s and s_N it might even become negative, though this is unusual.

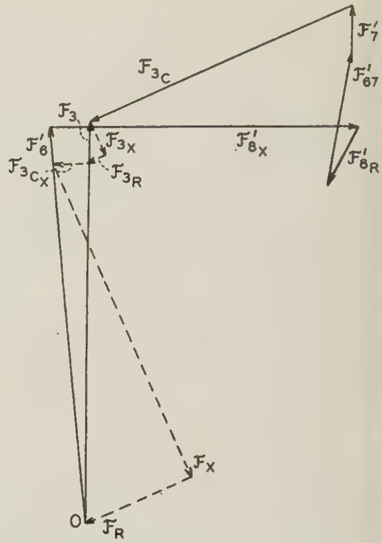
Determining Self Excitation From the Ampere Turns Diagram

It is now possible to draw the above-mentioned ampere turns diagram of the commutator machine by combining the properly changed vectors of figure 3. This diagram is shown in figure 4 for the Scherbius machine generating. Because the effect of subsynchronous or supersynchronous self excitation is taken into account by the load resistance R, such a diagram holds qualitatively for both senses of rotation of the self-excited field of the commutator machine.

Fig. 4. Ampere turns diagram of a Scherbius machine with exciter during self excitation

The ampere turns of the exciter are represented as equivalent ampere turns of the commutator machine

The dotted lines give the voltages of the armature and load circuit of the commutator machine expressed as ampere turns of the commutator machine



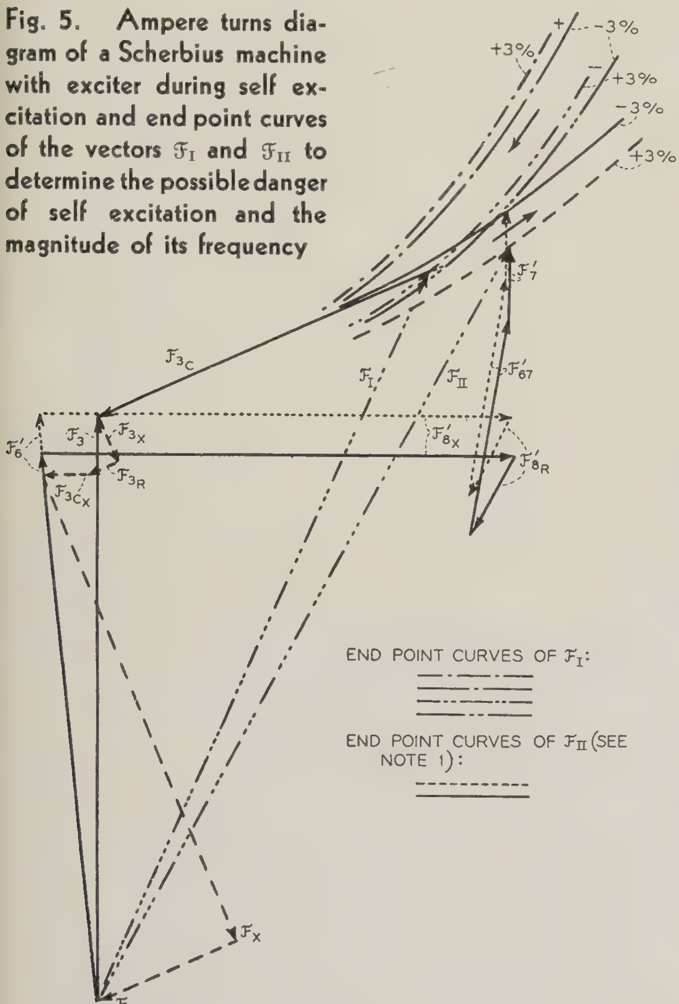
The voltages in the armature and load circuit of the commutator machine are reduced as shown in figure 4 by multiplication with the quotient of the resultant ampere turns $\mathfrak{F}_3$ and the electromotive force E_3 of the commutator machine. The sum of $-\mathfrak{F}_R - \mathfrak{F}_x$ is equivalent to the slip ring voltage. The ampere turns of the exciter have to be reduced in such a way that the ampere turns of the slip ring field are equal to the ampere turns representing the slip ring voltage plus a small correction which is necessary to take into account the effect of the ohmic drop in the field circuit of the commutator machine. For convenience these ampere turns of the exciter are divided into 3 groups. The first group is the ampere turns $\mathfrak{F}_6'$ and $\mathfrak{F}_7'$ proportional to the excitation voltages proper, i. e., the slip ring and frequency changer voltages. The second group is the 2 components of the resultant ampere turns of the exciter, one proportional to the total ohmic drop of the field current of the commutator machine $\mathfrak{F}_{8R}'$, the other one, $\mathfrak{F}_{8x}'$, proportional to the induced electromotive force in the field winding of this machine (the inductive voltage drop of the field current is neglected). The third group is the ampere turns $\mathfrak{F}_{67}'$ caused by the voltages induced in the 2 field windings of the exciter by its main flux (the leakage flux is neglected). This group is perpendicular to this flux, which is in phase with $-\mathfrak{F}_{8x}' - \mathfrak{F}_{8R}'$.

It can easily be shown that for constant flux of the commutator machine the following relations between the different vectors and the self-excited rotor frequency and the speed of the commutator machine hold. $\mathfrak{F}_{8X}'$ and $\mathfrak{F}_{3cX}$ are proportional to the frequency. $\mathfrak{F}_{67}'$ is, for a given ratio of flux to resultant ampere turns of the exciter, approximately proportional to

$\mathfrak{F}_{8x}'$ and the frequency; it increases, therefore, roughly with the square of the frequency. $\mathfrak{F}_7'$ and $\mathfrak{F}_{3c}$ decrease with increasing frequency and the lag of the latter is increased. By varying the speed of the commutator machine, $\mathfrak{F}_3$ and $\mathfrak{F}_{8x}'$ are not affected and $\mathfrak{F}_{67}'$ is only slightly affected. All other full drawn vectors are strictly or approximately proportional to this speed.

The danger of self excitation can now conveniently be discussed by dividing the vectors of figure 4 into 2

Fig. 5. Ampere turns diagram of a Scherbius machine with exciter during self excitation and end point curves of the vectors $\mathfrak{F}_I$ and $\mathfrak{F}_{II}$ to determine the possible danger of self excitation and the magnitude of its frequency



The solid vectors are for + 3 per cent slip, the dotted vectors for − 3 per cent slip

The + and − signs at the end point curves of $\mathfrak{F}_I$ stand for subsynchronous (+) and supersynchronous (−) self excitation

+3 per cent and −3 per cent designate the operating slip of the induction machine for which the end point curves are drawn

The arrows point in the direction of increasing self-excited rotor frequency

Note 1—For simplification the end point curves of $\mathfrak{F}_{II}$ are drawn identical for subsynchronous and supersynchronous self excitation

groups, each group vector starting from point O. $\mathfrak{F}_I$ is the difference $\mathfrak{F}_3 - \mathfrak{F}_{3c}$ and can be considered as the ampere turns necessary to produce the assumed voltage and current. $\mathfrak{F}_{II}$, being the sum of all other components, gives the ampere turns which the field circuits of the commutator machine and the exciter produce. Self excitation is only possible if $\mathfrak{F}_{II}$ is at least equal to $\mathfrak{F}_I$. The question whether self excitation is possible or not can therefore be answered by plotting the endpoint curves of the vectors $\mathfrak{F}_I$ and $\mathfrak{F}_{II}$ (see figure 5) for different speeds of the commutator machine within the operating range of the converter and for several self-excited frequencies. If such a diagram shows $\mathfrak{F}_{II}$ to be smaller than $\mathfrak{F}_I$ for a certain frequency for which the end points of $\mathfrak{F}_I$ and $\mathfrak{F}_{II}$ are approximately in line parallel to $\mathfrak{F}_3$, self excitation will not occur.

From this diagram a few interesting conclusions can be drawn. The most important ones are as follows:

The danger of self excitation increases with decreasing short circuiting effect of the network, decreasing ohmic component of the load, increasing speed of the commutator machine, and increasing flux and number of turns of the field windings of the exciter.

The self-excited rotor frequency increases with decreasing load inductance and increasing counter-compounding of the commutator machine and decreasing ratio of the resultant to the counter-compound ampere turns of the exciter.

Because of the number of variables it is not feasible to state numerically which converter would be self-excited and which not. It is, however, usually possible by properly applying the above conclusions to definitely eliminate the danger of self excitation in specific cases.

Some Factors Affecting Self Excitation

Of special interest is the increasing probability of self excitation with decreasing load resistance in the light of a previous statement that this resistance can become negative. As a machine loaded by a negative resistance is operating as a motor, the conclusion must be drawn that this Scherbius machine can be self excited and at the same time operate as a motor as long as the reactive load component is inductive. This is the more surprising as the load resistance of the commutator machine was negative when the losses in the network were particularly high. This apparent contradiction is easily cleared up when it is remembered that for supersynchronous operation of the induction machine and generator action of its stator the rotational field delivers to its rotor an amount of power equal to the stator power times the slip. If the stator and therefore the rotor power are large enough, all losses in the rotor circuit can be covered and in addition a certain amount of mechanical power given off. (For a similar discussion see reference 13.) All this power is supplied from the shaft of the induction machine and the Scherbius machine has indeed to supply only the magnetizing power in order to make self excitation possible.

Of similar interest is the other extreme when the network delivers a large amount of power to the stator of the induction machine. Because of the supersynchronous self excitation f_{2s}/f_{1s} times this stator power is supplied from the rotor to the rotational field of the induction machine. Both powers appear as mechanical output at the shaft of the in-

duction machine. This leads to the apparently paradoxical result that the generator output of the Scherbius machine rises with increasing generator output of its "load."

In this connection it should be pointed out that for a strong short-circuiting effect of the network, i. e., negligible frequency changer ampere turns, supersynchronous self excitation is more probable than subsynchronous self excitation. This is so because the load resistance R according to equation 1 (previously given) is smaller for supersynchronous self excitation on account of the negative values of s_s and s_N.

The physical reason for this difference of R is that the rotor of the induction machine with its stator generating is motoring for subsynchronous self excitation, and generating for supersynchronous self excitation. In the second case it is therefore reducing the losses to be covered by the Scherbius machine.

If the frequency changer ampere turns during self excitation are relatively large the sense of rotation of the self-excited rotor field is determined by the phase angle between the frequency changer and slip ring ampere turns, i. e., by the direction of the power transfer during normal operation. This sense will be such that the frequency changer ampere turns have a component in phase with the slip ring ampere turns. It can be easily shown that with the induction machine motoring during normal operation the self excitation will tend to be supersynchronous, with the induction machine generating subsynchronous.

If the induction machine be accidentally disconnected from its network, the load impedance of the Scherbius machine becomes high, about equal to the no-load reactance of the induction machine and the full frequency changer ampere turns are available. This will almost certainly produce self excitation. The rotor frequency under these conditions is rather low and the main fluxes of both the commutator and induction machine will probably rise to a very high saturation.

If the circuit breaker at the distant end of a transmission line should trip, the no-load impedance of the induction machine will be shunted by the capacity of the transmission line. This will increase the load inductance of the Scherbius machine and therefore decrease the self-excited rotor frequency. As before, self excitation is almost certain. It is, however, not so dangerous as it seems because it does not occur during normal operation. Secondly, normal operation could not be resumed before—among other things—the frequency changer circuit is adjusted to zero power transfer. As changes in the field circuits of the commutator machine have to be made anyway, it is not unreasonable to provide means which will produce these changes automatically in case of service interruption in order to stop immediately the self excitation of the disconnected converter.

Special Means of Compensating for Self Excitation

Under certain conditions it is possible that within an economical design the danger of self excitation cannot be entirely eliminated. In such cases it is necessary to introduce means by which the available excitation for the self-excited voltage is automatically decreased from its value for the normal frequency. According to Seiz this can be achieved by connecting a small unloaded induction machine with a large ratio of no-load to short-circuit impedance to a suitable point of the exciter circuits. Due to its low speed and special design it will always revolve virtually in synchronism with the normal rotor frequency and therefore be nearly a short circuit for any self-excited voltage of a frequency usually encountered.

Another method is to utilize the short-circuiting effect of the primary network during self excitation to reduce the available ampere turns of the slip ring field, which are largely responsible for the danger of self excitation of this converter. To this end, part of the voltage of the so-called slip ring excitation is introduced from the secondary of a small induction machine, coupled to the converter, the primary of which is supplied through a transformer from the primary voltage of the main induction machine.[13]

A third method is to feed an essentially capacitive auxiliary field circuit of the exciter from its terminal voltage (see page 27 of reference 12). Because both the electromotive force induced in the field windings of the exciter and the rotational electromotive force produced by this auxiliary circuit increase for constant flux of the commutator machine approximately with the square of the frequency, complete compensation of the electromotive forces induced in the field windings for any frequency is indicated. Before applying this method, however, it is necessary to check whether the auxiliary field current is small compared to the current which its ampere turns cause to flow in the field circuit of the commutator machine. Unless this is so, the auxiliary circuit is of no effect because the 2 currents oppose each other in the field circuit of the commutator machine.

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Improvements in Communication Transformers

The rapidly advancing art of electrical communication and the increasingly wide variety of its applications have required marked improvements in the transformers used in communication circuits. These improvements, achieved partly through advances in design and partly through improvements in the constituent materials, are discussed in this paper.

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THE rapid development of the art of electrical communication in the last decade has necessitated marked improvements in the transformers used in it. New applications for these transformers and the extension of old ones have imposed new and far severer performance requirements. The primary applications of communication transformers are in the telephone plant, in the various voice and carrier transmission circuits, and in a multitude of incidental services. They have also wide uses in radio broadcasting transmitters and receivers, in the amplifiers of sound motion picture equipment, in the radio equipment for aircraft, and in a variety of other circuits.

Although communication and power transformers have a common origin, the communication transformer now has evolved as a precision device which has only a general resemblance to the usual power transformer. Some voice frequency transformers, such as those used in aircraft, weigh but 2 or 3 ounces, yet transmit speech substantially undistorted. Some used in program circuits transmit with negligibly small phase or amplitude distortion all frequencies from 20 to 16,000 cycles per second. Transformers also have been developed for transmitting narrow bands of frequencies and having associated with the normal transformer performance valuable frequency discriminating properties. A discussion of improvements in these narrow band transformers is outside the scope of this paper, which will be confined to those transmitting wide frequency bands, that is, those for which the ratio of upper to lower limiting frequencies is at least 10 to 1.

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1. For all numbered references, see list at end of paper.

The design of the modern communication transformer is based upon extensions of the familiar theory of transformers covered in numerous texts. However, this type of transformer is a more complex device, with its multiplicity of requirements and its transmission over a wide frequency range. Its proper representation accordingly requires a more elaborate equivalent network than the customary Π or T network. With the use of such a network, the performance of the transformer may be correlated mathematically with its constants in accordance with network theory.

Improvements in Low Frequency Transmission

The great improvements in communication transformers, particularly at audio frequencies, are largely attributable to the invention and application of the permalloys as magnetic core materials. For convenience, the term "permalloy" has been applied to a group of nickel-iron alloys containing between 30 and 95 per cent nickel which have been developed by Bell Telephone Laboratories.[1,2,3] In addition to other desirable magnetic properties, some of these permalloys[4] when properly heat treated yield exceptionally highly initial permeabilities. As a result of the use of these special alloys, telephone transformers may be designed to have less loss and distortion over wider frequency ranges than has been possible in transformers designed without the benefit of use of such materials.

Figure 1 illustrates the excellence of performance resulting from the use of a special permalloy consisting of approximately 4 per cent chromium, 78 per cent nickel, and the remainder iron, in a trans-

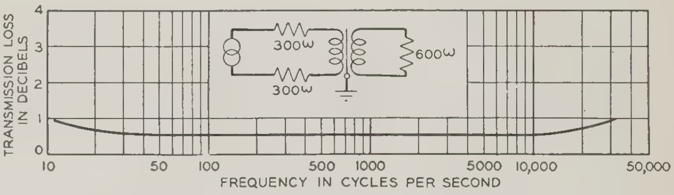

Fig. 1. Transmission-frequency characteristic of a transformer utilizing a permalloy core and designed to connect a telephone transmission line to a program repeater. Transmission loss shown is the loss relative to an ideal transformer of the same ratio

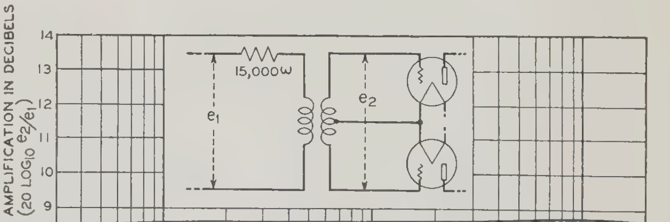

Fig. 2. Voltage amplification-frequency characteristic of an interstage transformer for a high quality program amplifier

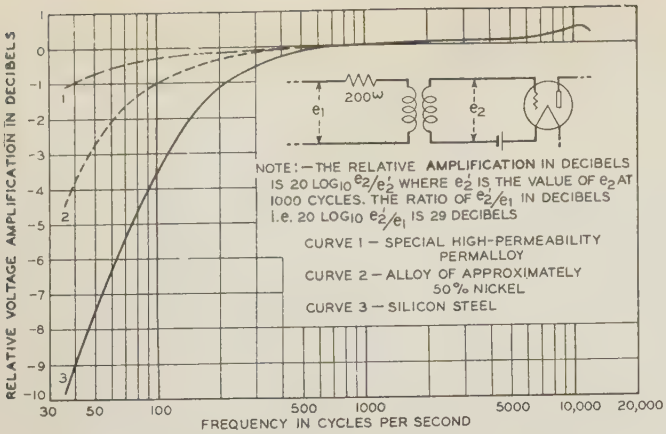

Fig. 3. Curves showing the relative effect of different core materials on the voltage amplification-frequency characteristic of a small transformer designed for portable recording apparatus. The composition of the special permalloy is approximately 4 per cent chromium, 78 per cent nickel, and the remainder iron

former designed to connect a telephone transmission line to a program repeater. Figure 2 shows the voltage amplification characteristic of an interstage transformer for a high quality amplifier. As is well known,[5] superimposed direct currents generally decrease the effective a-c permeability of ferromagnetic materials. Therefore, to retain the full benefit of the permalloy core, an auxiliary circuit was used with this transformer for supplying the plate current to the preceding tube. Another illustration is a transformer designed for use as an input transformer (that is, one designed to operate into the grid circuit of a vacuum tube) for portable recording equipment where light weight is an important consideration. The voltage amplification-frequency characteristic of this transformer is shown in figure 3. There is shown also in this figure, for purposes of comparison, the very much poorer characteristic realized when an alloy of about 50 per cent nickel as commonly used is substituted for the special permalloy. In addition, there is shown the effect of using silicon steel as core material, which was the practice in older transformers.

An important limitation of high permeability alloys is their sensitivity to mechanical strain which may seriously impair their magnetic characteristics. Considerable care must be exercised to avoid strain during assembly operations after laminations are annealed. Telephone transformers are designed specially to provide a firm assembly without mechanical strain, thereby retaining the high permeabilities available.

Increase in Voltage Amplification

As may be seen from the foregoing curves, the voltage amplification of input transformers at the low end of the frequency band is directly dependent on the permeability of the magnetic core material. At the highest frequencies the voltage amplification of the above input transformers is controlled by leakage and capacitances, the latter including grid circuit capacitances as well as the transformer distributed capacitances. Over a wide range in the central part of the frequency band these effects are negligible and the transformer performs much as an ideal transformer of the same ratio. By proper proportioning of the leakage and capacitance effects, the shape of the characteristic may be controlled to a certain measure at will. For example, a rising voltage amplification-frequency characteristic can be obtained if desired to correct for a falling characteristic of other parts of the amplifier.

In certain types of circuits the voltage amplification of input transformers is at a high premium, such as in the amplification of low energy signals when a-c power is used for the tubes. Under these conditions the tubes tend to introduce appreciable noise. A high voltage amplification in the input transformer serves to raise the signal voltage at the grid terminals so as to override the tube noises. Figure 4 shows that a high amplification, in this instance 10,000 to 1 in impedance level from a 30 ohm source, may be realized without undue restriction in either the low or the high frequency transmission.

Since transformers of this type are located at points of very low energy levels, special pains must be taken to avoid interference from stray magnetic and electrostatic fields. To prevent hum from nearby power apparatus, transformers are enclosed in cases or shields of high permeability material. The interference voltages induced in these transformers are some 30 or 40 decibels less than in older unshielded types of transformers. For higher frequency interference, effective shielding is obtained by cases made of high conductivity material such as copper or aluminum.

Reduction in Size and Weight

The demand for lightweight equipment for aircraft communication and for portable apparatus for testing and recording has resulted in the development of communication transformers of unusually small size and weight. The smaller sizes weigh only $3^1/_2$ ounces and occupy a space of but 3 cubic inches. One of these used in aircraft receiving sets is illustrated in figure 5 contrasted with an earlier transformer also for lightweight service. The transmission loss-frequency characteristics are shown in figure 6. The corresponding characteristic of an input transformer for similar service is shown in figure 7.

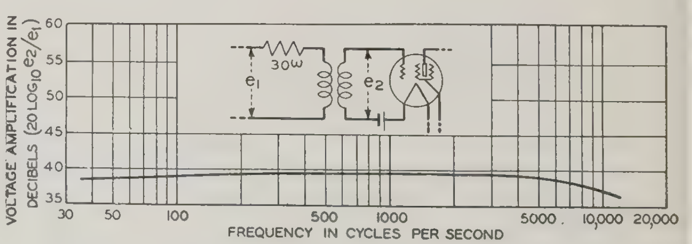

Fig. 4. Voltage amplification-frequency characteristic of an input transformer having an impedance ratio of 10,000 to 1

Extension of Range to Higher Frequencies

The effective permeabilities of alloys of high initial permeabilities drop rather rapidly with frequency, a property which lessens the value of such alloys in transformers for carrier and higher frequencies. This effect, which is attributable primarily to eddy currents, can be greatly decreased, of course, by the use of thinner laminations. The use of these alloys, however, is limited by the rapidly increasing cost of reducing the lamination thickness and the less efficient use of the volume available for the core. This dropping off of effective permeability with frequency is not so important in audio frequency transformers, since there the core characteristics limit the transmission only at low frequencies where the effective permeability is high.

At higher frequencies the voltage amplification is severely limited also by the grid circuit and transformer capacitances. It has been found advantageous to add correcting elements, such as inductances and capacitances, to increase the gain ordinarily available. These added elements and the equivalent elements in the transformer are designed together as configurations similar to low-pass filter sections terminated midshunt in the grid circuit capacitance. Figure 8 illustrates the performance of a transformer designed for certain high frequency transmission experiments. The performance of this transformer in the frequency range of 30–500,000 cycles per second is similar to that of earlier types in the range of 30–60,000 cycles per second.

In most telephone applications the design of input transformers is complicated greatly by circuit functional requirements in addition to those of direct transmission. For example, as discussed in a succeeding section of this paper, phase distortion requirements demand self-impedances far higher than those required by transmission loss considerations, thermal[6] noise requirements demand lower dissipations, and impedance requirements limit the voltage amplification obtainable. For feed-back type amplifiers[7] the input transformers in addition to the forward amplification must meet transmission and phase requirements in the regenerative path. These special requirements apply not only for the transmitted frequency band but also at frequencies remote from this band in order to insure stability of the amplifier.

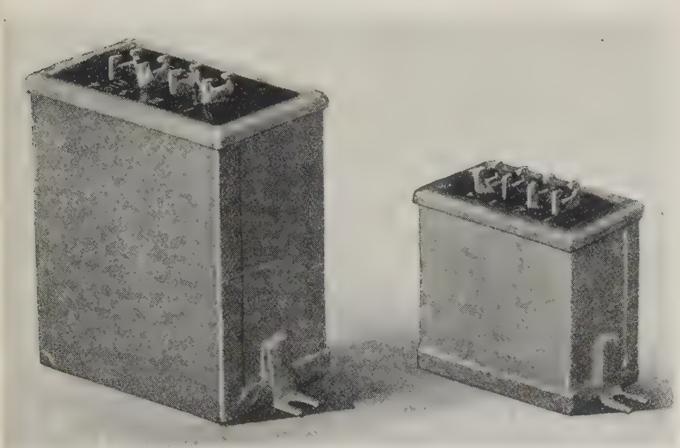

Fig. 5. Output transformer A (right) utilizing a permalloy core transmits frequencies from 40 to 3,000 cycles with greater over-all efficiency than the larger output transformer B (left) utilizing a core of silicon steel (see figure 6)

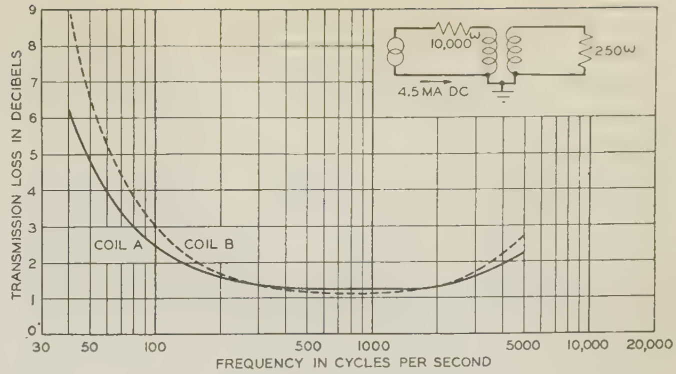

Fig. 6. Curves showing the transmission loss-frequency characteristics of (A) the small output transformer and (B) the larger output transformer shown in figure 5

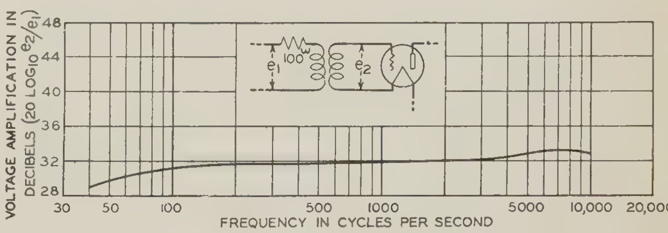

Fig. 7. Voltage amplification-frequency characteristic of an input transformer similar in size to the smaller output transformer shown in figure 5

Reduction in Phase Distortion

Since transformers are reactive devices, they introduce phase shift in the circuits in which they are used. If the phase shift introduced be a linear function of the frequency it will not produce any distortion in the shape of the transmitted wave. However, departures from linearity change the wave shape, and this form of distortion is referred to as phase or delay distortion. The delay at any frequency is a measure of this departure from linearity, and is dependent upon the frequency derivative of the phase shift at that frequency. Differences in delay of the various frequency components of the signal wave which transformers tend to produce result in distortion that may be especially serious in circuits intended for program transmission.

For wide band transformers the delay caused by the shunting effect of the mutual impedance usually predominates. In fact for audio transformers the delay at higher frequencies is relatively so small that the delay distortion is practically equal to the mutual impedance delay at the lowest transmitted frequency. Delay distortion is also of importance in trans-

formers to be used in television and telephotography. In these circuits phase distortion causes a space shift in the image of certain frequency components with respect to others with consequent blurring of the image.

The delay characteristic of a transformer used in program circuits to connect a telephone transmission line to the grid circuit of a repeater amplifier is shown in figure 9. This characteristic is compared in the same illustration with the delay characteristic of a repeater transformer developed some years ago for use in what then was regarded as a high quality circuit. The delay characteristic of a high frequency transformer is shown in figure 10.

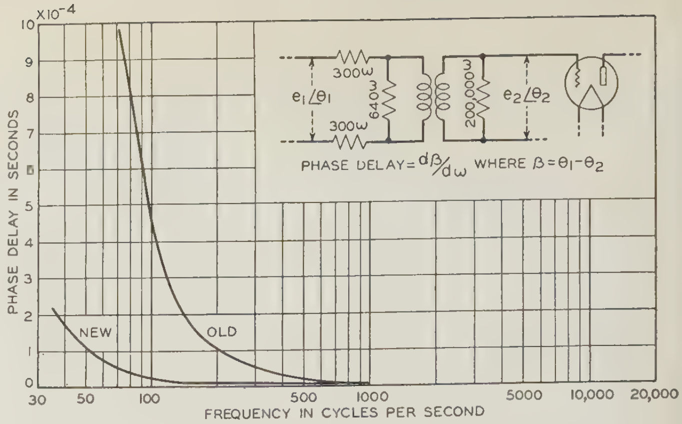

Fig. 9. Phase delay-frequency characteristic of an input transformer used in recent program repeaters, compared with that of an input transformer used in an older repeater

Reduction in Audio Frequency Modulation

The present exacting requirements for transformer performance have made it necessary to lessen greatly certain second-order distortion effects inherent in transformers having magnetic cores. Nearly all core materials tend to generate extraneous frequencies because of magnetic nonlinearity—a property referred to as magnetic modulation. In audio frequency circuits intended for high quality service, magnetic modulation may cause serious distortion in that harmonics of the lower frequencies appear higher in the audible range. The energy present at the lower frequencies is usually so much greater than that over the rest of the band that the modulation products may approach the order of magnitude of the signal components at higher frequencies.

This form of distortion in no way is revealed by the ordinary transmission loss characteristic; in fact, a transformer having a very flat loss characteristic over a wide frequency range may nevertheless be definitely objectionable from a modulation standpoint. In present audio frequency transformers, the total modulation products are some 40 to 80 decibels down from the energy of frequencies around 35 cycles per second producing them. This represents an improvement of about 30 decibels over older types.

Another second order effect resembling modulation is microphonic noise caused by magnetostriction phenomena, that is, changes in magnetization accompanying the physical deformation of the magnetic material. For instance, slight jarring of input transformers used in very high gain amplifiers (100 decibels or more) may induce in this manner disturbing noise voltages. Freedom from magnetostriction is a unique characteristic of permalloys containing approximately 80 per cent nickel, and their use accounts for the superiority of telephone transformers from this standpoint.

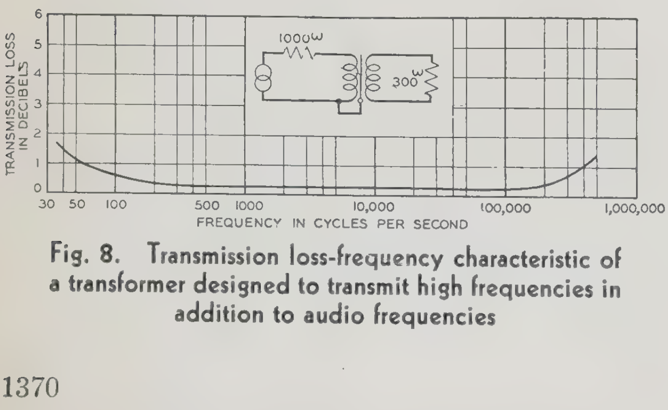

Fig. 8. Transmission loss-frequency characteristic of a transformer designed to transmit high frequencies in addition to audio frequencies

Reduction in Carrier Frequency Modulation

Magnetic modulation is even more serious at carrier frequencies where a transformer may transmit many channels, frequently at widely different levels. The modulation from the higher level channels may produce very objectionable interference in other channels. Carrier transformers now have been improved to such an extent that highly sensitive testing circuits are required to detect and measure the modulation products contributed by them. Representative values of these modulation products expressed as current ratios to the fundamentals are of the order of one millionth of the fundamental frequencies, compared to one thousandth in older types.

It is of interest to point out that in such transformers the presence of magnetic material, other than the special permalloys, in the vicinity of the transformer must be avoided with great care. For example, a small steel screw near the field of the transformer will seriously impair its performance from a modulation standpoint. Common practice is to use brass parts for the assembly and to confine the field of the transformer by completely enclosing it in a copper or aluminum case. The transformer then may be mounted by any convenient means without affecting its performance.

Improvements in Shielding and Balance

In the very nature of the service that it renders, the telephone plant involves many independent communication circuits in fairly close proximity. The minimizing of interference between these independent communication circuits has constituted a major problem in telephone engineering. Where such interference occurs between like circuits, that is, between 2 voice circuits or between 2 carrier circuits of overlapping frequency bands, the interference commonly is referred to as cross talk, as distinguished from the

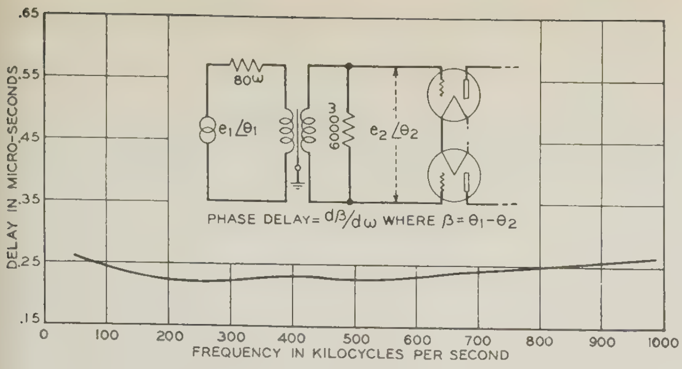

Fig. 10. Phase delay-frequency characteristic of an input transformer designed to transmit radio frequencies

interference from other types of circuits such as power and telegraph circuits.

In order to avoid cross talk and other interference, balanced* circuits are used almost exclusively in the telephone plant. For simplicity, some of the terminal apparatus connected with these circuits is constructed unbalanced, so that it is necessary to interpose transformers between the lines and the office equipment, these transformers providing a barrier to the propagation of the relatively large longitudinal currents from the line circuits. (Longitudinal currents, in contrast with the usual circulating currents, are currents that flow equally and in the same direction in both sides of the line.) In order to insure that the voltage impressed on the office equipment is attributable to the voltage between the wires of the line circuit and not to that between the wires and ground, it is necessary that the transformers be balanced very carefully; and for certain types of circuits, shields must be interposed so that the direct capacitance between the line winding and office winding is reduced to a very small value.

With a greater emphasis on carrier frequency transmission, a higher degree of balance is required between certain transformer windings, and highly effective shielding is frequently necessary. It is necessary also that the line windings be balanced very closely with respect to capacitances to the shield and case. The unbalance effects in carrier transformers now have been reduced to values in the order of 1 or 2 microamperes in circulating current per volt between the line windings and ground at 30,000 cycles per second, which compares with values of 50 microamperes or more for older transformers. At the same time the electrostatic shielding between the windings has been reduced to 1 or 2 micromicrofarads instead of 30 or 40 as before. The shields are arranged to intercept the dielectric flux lines tending to connect the primary and secondary windings, so that the direct capacitance between the 2 windings is attributable only to stray flux which by-passes the shield. One of the windings usually is enclosed completely in lead or copper foil with overlapping edges insulated to prevent a short-circuited turn. Still further improvements are obtained by covering the leads with grounded metal braiding, and in special cases by enclosing the terminals of the shielded winding in a separate shielded compartment. In certain transformers designed for high precision testing equipment, the direct capacitance between windings has been reduced to values less than 0.001 micromicrofarad.

In connection with phantom circuits, severer cross talk requirements have necessitated more precise balances in the associated voice frequency transformers. In these transformers the turns are so arranged that the various distributed capacitances, flux linkages, and d-c resistances are disposed symmetrically with respect to ground. It has been found in practice that this symmetry is realized most readily by close coupling between the various parts of the windings. By improvements in design, the cross talk between phantom and side circuits has been reduced to values in the order of 20 millionths in current ratio compared to values 5 times as large formerly tolerated.

Reduction in Impedance Distortion

As a further consequence of the extension of carrier systems, it has become necessary to match the impedance presented by transformers, when terminated in the succeeding circuits, to particular values over the frequency range. For example, the transposition schemes used on open wire lines are such as to minimize cross talk primarily for carrier signals propagated in one direction in any line. If the transformer terminating such a line does not present an impedance under load equal to the characteristic impedance of the line, a portion of the wave is propagated in the reverse direction, that is reflected, causing cross talk into adjacent circuits. This reflection effect increases with the vector difference in the impedances of the transformer and the line, the latter impedance approaching a pure resistance as the frequency increases.

The impedance of transformers has become increasingly important where such transformers terminate filters that require a nearly constant resistance termination to maintain proper attenuation characteristics. Another example is in transformers terminating

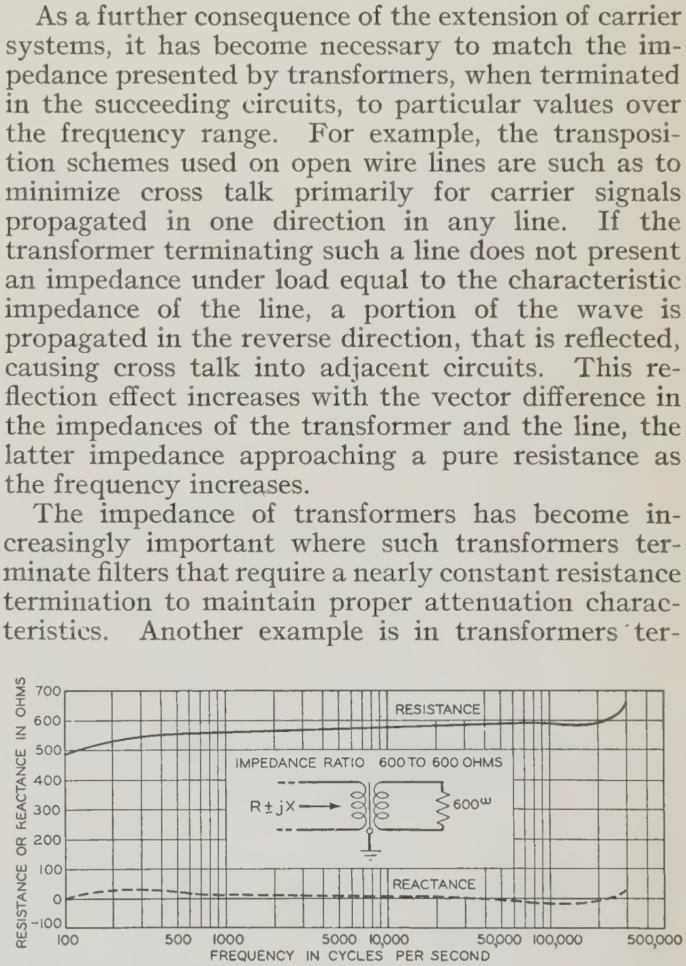

Fig. 11. Impedance-frequency characteristic of a transformer designed to operate between 600 ohm terminations and to transmit high frequencies in addition to audio frequencies

* The new coaxial cable circuits under development are an interesting exception. In this type of cable a grounded outer conductor completely encloses the central conductor, and shielding rather than balance is relied upon to protect the circuit from interference. The shielding depends upon the size, thickness, permeability, and conductivity of the outer conductor and the frequency of the disturbance. If the frequency band used in the transmission over coaxial circuits is chosen properly, the circuit may be made substantially immune to effects from outside fields.

minating screen grid tubes where the plate impedances are relatively very high. Here the energy abstracted from the plate circuit and transmitted by the transformer is directly dependent upon the resistance component of the impedance of the transformer when terminated in its load.

Better impedance characteristics of transformers for these various applications have been obtained by increasing the mutual impedance and decreasing the leakage and capacitance effects. This procedure is made difficult by the necessity for meeting at the same time other and newer requirements, as, for example, modulation limits. Correcting elements consisting of capacitances and inductances usually are added and are proportioned with the transformer elements in accordance with network theory. Typical impedance characteristics of such transformers are shown in figures 11 and 12.

Input transformers operating into the grid circuits of vacuum tubes inherently have impedances that depart widely from the nearly pure resistances usually desired, because of the reactive termination provided by the grid circuit. This makes it necessary to add resistances to serve in place of the usual load resistance. The required dissipation may be provided in many ways in the input transformer, which consideration allows much wider latitude in the design than in the ordinary transformer; there the major part of the dissipation for low transmission loss necessarily must occur in the load. A typical impedance characteristic of such an input transformer is shown in figure 13.

Testing Precautions

As a necessary concomitant to improvements in transformers, more precise testing circuits have been developed for accurately determining transformer performance. In estimating the performance of the transformer from its characteristic, care must be taken to make sure that the service conditions were reproduced carefully in the measuring circuit. In particular, certain precautions must be observed in the measurement in order to avoid obtaining a misleading characteristic. For example, the permeability of magnetic core materials tends to rise rapidly from its initial value with increasing voltages. If in the measurement, the low frequency voltages used are materially higher than they are under service conditions, the low frequency response will appear to be much better than the true response.

As another example, the transmission of input transformers at the high frequency end may be critical with the termination of the high voltage winding. If the grid capacitance and conductance conditions are not reproduced faithfully in the measuring circuit, the high frequency voltage amplification may appear to be much better than the true value.

In addition to more precise transmission measuring circuits, various other special circuits have been developed for measuring transformers, such as modulation, impedance, and cross talk measuring circuits. The design of these circuits is of necessity a specialized art.

In the foregoing, various types of improvements in communication transformers have been discussed. Wherever applicable, several such improvements have been incorporated in an individual design. The improved performance of transformers as described has been an essential step in the development of the communication art.

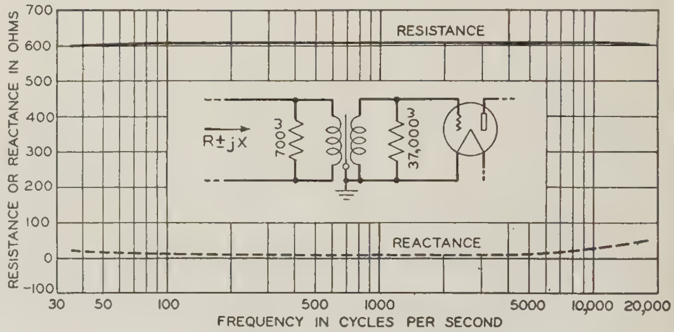

Fig. 13. Impedance-frequency characteristic of an input transformer used to operate from a telephone transmission line into a high quality program repeater. Impedance ratio is 600 to 15,000 ohms

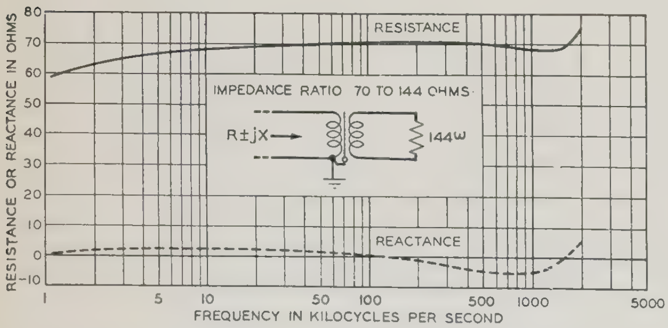

Fig. 12. Impedance-frequency characteristic of a transformer designed to operate between resistance terminations of 70 ohms and 144 ohms

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I.E.C. Adopts MKS System of Units

At its plenary meeting of June 1935 at Scheveningen-Bruxelles, the International Electrotechnical Commission unanimously adopted the meter-kilogram-second (mks) or Giorgi system of units, 15 of the 25 constituent countries being represented. In this paper the principal historical antecedents of this action by the I.E.C. are outlined, and its principal import to electrical engineering is indicated. Since the preparation of this paper there have been further important developments in connection with the adoption of this system; reports of these developments, as translated from the original French texts, are given in appendixes I and II.

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As IS WELL KNOWN, the International Electrotechnical Commission is an international organization maintained by 25 countries. It was called into existence under the leadership of R. E. Crompton, in response to a recommendation of the International Electrical Congress of St. Louis (Mo.) in 1904. It was organized in 1906 with its secretariat in London, and C. LeMaistre has been its general secretary since that time. It comprises 24 advisory committees, each dealing with a particular electrotechnical subject, and it has held plenary meetings in London, Paris, Brussels, The Hague, Berlin, Cologne, Turin, Zurich, Bellagio-Rome, Geneva, Denmark, Scandinavia, and New York. It has accomplished much international electrotechnical work during its 29 years of activity.

At its plenary meeting, in June 1935, at Scheveningen-Bruxelles, the I.E.C. unanimously adopted the Giorgi System of meter-kilogram-second (mks) units, 15 countries being represented by the delegates present. Every electrical engineer should make himself acquainted with the significance of this decision. In effect, it replaces the 3 systems at present in use (namely, the absolute electromagnetic cgs system, the absolute electrostatic cgs system, and the practical series) by one practical system.

The fundamental units are so chosen that the present practical series or system becomes at once an absolute system. This brings about a great simplification in the teaching of units and in practical calculations.

For the present, the question of rationalization has been left for future consideration. As the permeability and permittivity of space are no longer unity, it would be an easy matter to fix their values so as to rationalize all calculations; that is to say, to arrange matters so that the multiplier 4π comes into those formulas only where it would be expected to enter.

Not since the International Congress of Electricians, at Paris[7] in 1881, has there been made a decision of similar international significance. It is the purpose of this paper to outline the principal historical antecedents of this I.E.C. action, to indicate its main import to electrical engineering, and to suggest a few of the implications it may involve. The account here given is, however, necessarily subsidiary to the official minutes of the meeting, which should be consulted by interested readers.

History of CGS and Practical Units

As early as 1848, resistance boxes had been produced in Germany, calibrated to correspond to the linear resistance of particular sizes of telegraph wire. Gauss and Weber, about 1850, showed how to make certain electric and magnetic measurements in absolute measure, adopting for this purpose the millimeter-milligram-second system (mms). In 1860, Werner Siemens introduced his mercury unit of resistance; i. e., a glass tube of one square millimeter cross sectional area and one meter long, filled with pure mercury, at zero degrees centigrade.

The British Association for the Advancement of Science (commonly abbreviated to B.A.), at its meeting in Manchester, of 1861, established a committee to report upon "standards of electrical resistance." This B.A. committee became famous for its pioneer work. It made annual reports[1] until 1867. It recommended the adoption of an absolute fundamental system of scientific units, and after trying the foot-grain-second system (fgs) advocated the meter-gram-second system (mgs). It computed theoretically, and worked out practically, approximate electric standards, especially that of electrical resistance, for which Latimer Clark suggested the name *ohm*. Because the mgs absolute electromag-

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Scheduled for republication by the Institution of Electrical Engineers, London.

7. For all numbered references see list at end of paper.

netic unit of resistance was found to be an extremely small quantity in reference to practical needs, this committee recommended that the practical unit of resistance (or *ohm*) should be 10^7 of these units, since 10 such *ohms* would be roughly equal to the resistance of one mile of an ordinary size of telegraph wire. Telegraph engineering was at that date almost the only existing application of electrical science. The demand for electrical units came from telegraph engineers. Again, since the mgs electromagnetic unit of electromotive force was extremely small from a telegraph-engineering standpoint, another large decimal multiple, 10^5, was recommended for the practical unit, with the name *volt*, since about 100,000 such mgs units were roughly equal to the electromotive force of one Daniell voltaic cell. The decimal factors 10^7 and 10^5 were purely arbitrary and adventitious, to meet the needs and convenience of these particular applications; but once the *volt* and *ohm* were adopted, a new strong influence came into effect, namely, systematic connection between the practical units, such, for example, that the *volt* acting in a circuit of one *ohm*, should deliver one practical unit of current. This would mean that the rest of the practical units were no longer arbitrary, but assigned themselves in accordance with the laws of physics, in one-to-one unit relations. Thus the literature shows that the original value of the *farad*, as the B.A. practical unit of capacitance, was equal to what now is called the *microfarad*, taken as an arbitrary convenient magnitude for telegraph practice; but this was changed[2] later to the present magnitude of the *farad*, because of considerations of systematic relations.

The second B.A. committee was appointed in 1868, "for the selection and nomenclature of dynamical and electrical units." It proceeded to discuss and compare the relative advantages of the cgs, mgs, fgs, and mms systems, for the purposes of a comprehensive fundamental system adapted for use in all branches of science. Its first report—an important document—was published[3] in 1873. It decided, after much debate, in favor of the cgs system. A principal reason for this choice was that the cgs system was the only one of the 4 considered that gave the unit of density equal to that of pure water at standard temperature and pressure (one gram per cubic centimeter). The practical units with standards already in use among practitioners—*ohm*, *volt*, and *farad*—were converted from the mgs multipliers 10^7, 10^5, and 10^{-7}, to the corresponding cgs multipliers 10^9, 10^8, and 10^{-9}, as they exist today. The report also advocated 3 names for as many cgs units, namely, the *dyne* for unit force, the *erg* for unit work, and the *erg per second* for unit power. These names also remain in use.

Although the cgs system and its appended practical units gained recognition among scientists and electrotechnicians, no international action was taken on them until the First Electrical Congress at Paris, in 1881. This memorable congress[7] adopted the cgs electromagnetic units as fundamental, and 5 practical units decimally derived therefrom: the *ohm*, *volt*, *ampere*, *coulomb*, and *farad*. Steps were taken to produce a standard *ohm* as a mercury

Glossary of Abbreviations

I.E.C.	International Electrotechnical Commission
B.A.	British Association for the Advancement of Science
I.P.U.	International Union of Pure and Applied Physics
S.U.N. committee	Committee on symbols, units, and nomenclature of the I.P.U.
N.P.L.	National Physical Laboratory (British)
E.M.M.U. committee	Electric and magnetic magnitudes and units committee of the I.E.C.
I.C.W.M.	International Committee of Weights and Measures
C.C.E.	Comité Consultatif d'Electricité of the I.C.W.M.
mks	meter-kilogram-second (system)
cgs	centimeter-gram-second (system)
fgs	foot-grain-second (system)
mgs	meter-gram-second (system)
mms	millimeter-milligram-second (system)
qes	(earth-quadrant)-(eleventh-gram)-second (system)
cg-ss	centimeter-(gram-seven)-second (system)

column resistor of one square millimeter cross section at standard temperature and pressure. The 5 practical units formed a series in one-to-one relation. The cgs system thus became the great fundamental absolute system for universal measurements in all branches of physical science.

Since 1881, 4 more units have been added to the practical electrical series: the *joule*, *watt*, *henry*, and *weber*, in 1889, 1889, 1893, and 1933, respectively, the first 3 at international electrical congresses, and the fourth by the I.E.C. at Paris (confirmed this year at Brussels).

Comprehensive Practical Unit Systems

Clerk Maxwell, who placed the classical cgs systems (electric and magnetic) on a firm mathematical basis, pointed out,[6] in 1881, that the practical series of electromagnetic units virtually formed a complete electromagnetic system, in which the unit of length was the earth-quadrant (10^9 centimeters), the unit of mass 10^{-11} gram (eleventh-gram), and the unit of time the mean solar second. The numerical value of space permeability in this qes system of Maxwell was $\mu_0 = 1$, the same as in the cgs magnetic system. This conception of the practical series as part of a magnetic system was interesting, but merely a proposition in the theory of units. Neither Maxwell nor any other theorist ever seriously proposed that the qes system should be adopted in practical scientific work, because the fundamental units of length and mass were so awkward. For instance, with unit electric current strength as one *ampere*, the unit of current density would be the *ampere per square earth quadrant!* Maxwell's discovery remained, therefore, an academic curiosity.

G. Giorgi of Rome pointed out,[12] in 1901, that if the value of space permeability μ_0 were taken not as unity but as 10^{-7} unrationalized, or as $4\pi \times 10^{-7}$ rationalized, the practical series fell into an electromagnetic system like the qes system, and parallel to the magnetic cgs system, with unit length equal to the international meter (10^2 centimeters), unit mass equal to the kilogram, and unit time the mean solar second. Giorgi presented a paper on this new

mks system to the International Electrical Congress[15] of St. Louis, in 1904. A colleague of his, Ascoli, presented another paper[14] to the St. Louis congress, pointing out that there existed an indefinitely long series of such systems, all containing the practical series of units, such that if the system length unit were 10^l centimeters and its mass unit 10^m grams: then the equation of condition was $2l + m = 7$. In Giorgi's mks system, $l = 2$ and $m = 3$: while in Maxwell's qes system, $l = 9$ and $m = -11$. In this indefinite series of possible systems, all embracing the internationally adopted practical units, only Maxwell's qes system kept $\mu_0 = 1$, and only Giorgi's mks system comprised the international standards of length and mass maintained by the International Bureau of Weights and Measures at Sèvres, in the Park of St. Cloud, near Paris. Moreover, only Giorgi's mks system offered units of length and mass that were satisfactory practically.

The Giorgi mks system slowly advanced in favor all over the world. It was endorsed by several physicists in Europe. In the United States, G. A. Campbell came forward[24] heartily in support of the "definitive system," which differs from the Giorgi system only in details of definition. The only seriously advanced objection to it, setting aside the complaint that the Giorgi system fundamental equations are dissymmetrical from the standpoint of theoretical physics, seems to have been that its unit of density is the kilogram per cubic meter, which is 1,000 times smaller than that of pure water under standard specifications. Since the recent discoveries, however, of deuterium and of "heavy water," the argument for unit-density water has lost some force. To have the density of distilled water unity is, of course, an asset to a system of units; but its loss is not disastrous. The great bulk of water on the earth is ocean water, with a density distinctly greater that that of one gram per cubic centimeter; moreover, tables of specific gravity with that of pure water taken as unity are the same in the mks system as in the cgs system, and for engineering purposes specific gravities are likely to be more useful than absolute densities.

In or about the year 1916, proposals appeared to adopt another comprehensive system, sometimes[21] called "international system," based upon the centimeter as length unit, the gram-seven or 10^7 grams (10 metric tons) as mass unit, and the mean solar second as the unit of time (cg-ss system). Here $l = 0$ and $m = 7$. Several proponents have been named for this system, among them Blondel, Dellinger, Bennett, Karapetoff, and Mie. In the cg-ss system, the numerical value of space permeability μ_0 would be 10^{-9} unrationalized, and $4\pi \times 10^{-9}$ rationalized. Various papers and at least one book[22] have been printed on this system, which claimed many of the advantages of the Giorgi system. Its principal disadvantage, however, was the awkwardly large size of its unit of mass.

Magnetic Units

In reference to the history of practical magnetic units, it may suffice here to point out that as early as 1889, the Second Electrical Congress of Paris discussed the adoption of units for magnetic flux and flux density in the practical system, with personal names for both; but no action was taken in the matter at that time. Similar suggestions were made at the Third International Electrical Congress, of Frankfort, in 1891, but again without action being taken. At the Fourth International Electrical Congress, of Chicago, in 1893, certain proposals of the A.I.E.E., to adopt magnetic units in the practical series for magnetomotive force, flux, flux density, and reluctance, were considered; but the chamber of delegates recommended[9] that magnetic units should be restricted to the cgs system, and without specific names.

At the Fifth International Electrical Congress, of 1900, in Paris, names were requested for cgs magnetic units. There was considerable difference of opinion, and debate. Finally, the congress adopted the names *maxwell* for the cgs unit of magnetic flux, and *gauss* for the cgs unit of magnetizing force H. There was also some accidental misunderstanding of the action taken, some of the delegates present having supposed that the name *gauss* had been adopted for flux density B. No further international action on magnetic units took place thereafter, until the matter was taken up in 1927 by the I.E.C.

Actions of the I.E.C. and the International Union of Pure and Applied Physics (I.P.U.), in Reference to Magnetic Units. At its Bellagio[25] meeting in 1927, the I.E.C. discussed certain proposals relating to magnetic units. In view of much manifest difference of opinion, a subcommittee was appointed to consider and report upon the subject. The committee, composed of representatives from different countries, endeavored to reach conclusions by correspondence; but this was found to be impracticable because of the marked differences of opinion as to the meaning of terms used in magnetic literature and especially as to the meaning of the unit name *gauss*. These differences affected not only the literature of different countries, but also of different writers in each of several countries. The matter therefore was brought to the attention of the various I.E.C. national committees and placed on the agenda of the next I.E.C. meeting, in Scandinavia (1930).

After considerable discussion in Copenhagen and Stockholm, the committee decided unanimously[28] that, for electrotechnical purposes, the convention should be established that in free space the quantities flux density B and magnetizing force H should be taken as physically different; so that their ratio, the space permeability μ_0, was a physical quantity with dimensions and not a mere numeric. The same convention was applied to the absolute permeability μ of a simple magnetic medium; so that its relative permeability μ/μ_0 was dimensionless, or a mere numeric. The committee then assigned the unit name *gauss* to flux density B, confirmed the name *maxwell* for magnetic flux Φ, and gave the new international name *oersted* to the unit of magnetizing force H, all in the classical cgs system. These recommendations were confirmed unanimously by the I.E.C. plenary convention at Oslo, in July 1930. This Oslo convention gave satisfaction to the great

Table I—Incomplete List of MKS Units and of Corresponding CGS Units

No.	Quantity	Symbol	MKS Unit	CGS Unit	CGS Units in One MKS Unit
Mechanical					
1	Length	L	meter	centimeter	10^{2}
2	Mass	M	kilogram	gram	10^{3}
3	Time	T	second	second	1
4	Area	S	square meter	square centimeter	10^{4}
5	Volume	V	cubic meter (stere)	cubic centimeter	10^{6}
6	Frequency	f	hertz (cycle per second)	cycle per second	1
7	Density	d	kilogram per meter	gram per cubic centimeter	10^{-3}
8	Specific gravity		numeric	numeric	1
9	Velocity	v	meter per second	centimeter per second	10^{2}
10	Slowness		second per meter	second per centimeter	10^{-2}
11	Acceleration	a	meter per second per second	centimeter per second per second	10^{2}
12	Force	F	— (joule per meter)	dyne	10^{5}
13	Pressure	p	— (joule per cubic meter)	dyne per square centimeter, barye	10
14	Angle	α, β	radian	radian	1
15	Angular velocity	ω	radian per second	radian per second	1
16	Torque	τ	— (joule per radian)	dyne $\perp$ centimeter	10^{7}
17	Moment of inertia	J	kilogram-square meter	gram-square centimeter	10^{7}
Energetics					
18	Work or energy	W	joule	erg	10^{7}
19	Angular work, $\tau\alpha$	W	joule	erg	10^{7}
20	Volume energy	w	joule per cubic meter	erg per cubic centimeter	10
21	Active power	P	watt	erg per second	10^{7}
22	Reactive power	jQ	var	erg per second	10^{7}
23	Vector power, $P \pm jQ$		watt $\angle$	erg per second	10^{7}
Thermal					
24	Quantity of heat	Q	kilogram-calorie	gram-calorie	10^{3}
25	Temperature	θ	degree centigrade or Kelvin	degree centigrade or Kelvin	1
Luminous					
26	Intensity	I	candle	candle	1
27	Luminous flux	ψ	lumen	lumen	1
28	Illumination	E	lux	phot	$10\ ^{4}$
29	Brightness	b	candle per square meter	stilb	10^{-4}
30	Focal power		diopter		10^{-2}
Electrical					
31	Electromotive force	E	volt		10^{8}
32	Potential gradient	$\mathcal{E}$	volt per meter		10^{6}
33	Resistance	R	ohm		10^{9}
34	Resistivity	ρ	ohm-meter		10^{11}
35	Conductance	G	siemens, mho		10^{-9}
36	Conductivity	γ	siemens per meter, mho per meter		$10\ ^{11}$
37	Reactance	jX	ohm		10^{9}
38	Impedance, $R \pm jX$	Z	ohm $\angle$		10^{9}
39	Quantity	Q	coulomb		10^{-1}
40	Displacement	Q	coulomb		10^{-1}
41	Current	I	ampere		10^{-1}
42	Current density	i	ampere per square meter		10^{-5}
43	Capacitance	C	farad		10^{-9}
44	Specific inductive capacity	ϵ/ϵ_0	numeric	numeric	1
Magnetic					
45	Magnetic flux	Φ	weber	maxwell	10^{8}
46	Flux density	B	weber per square meter	gauss	10^{4}
47	Inductance	L	henry		10^{9}
48	Relative permeability	μ/μ_0	numeric	numeric	1

NOTE: Various units used in acoustical engineering, radio engineering, and mechanical engineering are omitted from this list.

majority of electrotechnicians all over the world; but the satisfaction among physicists has been less complete.

The International Union of Pure and Applied Physics (I.P.U.), at its Brussels meeting of July 1931, appointed, for the first time, a committee on "symbols, units, and nomenclature" (S.U.N.). This important S.U.N. committee has held several meetings of great value to the physical sciences. Its president has been Sir Richard Glazebrook, and its secretary, E. Griffiths, of the National Physical Laboratory (N.P.L.). The I.E.C. requested the I.P.U. for the co-operation of the S.U.N. committee in the matter of magnetic units, and this co-operation very courteously was granted. The S.U.N. committee proceeded to prepare a questionnaire on "electrical units," addressed to physicists and physical societies in different countries, calling attention to certain ambiguities in the definitions of fundamental electric and magnetic quantities entering into the classical cgs system, and inviting opinions as to how these ambiguities might be eliminated, in order to arrive at international agreement. This printed document[40] was issued by the S.U.N. committee in December 1931, and replies thereto were collected and distributed to the I.P.U. committees, as well as to the national committees of the I.E.C.

The electric and magnetic magnitudes and units (E.M.M.U.) committee of the I.E.C. met in London, September 1931, to consider the Oslo recommendations made by the same committee in July 1930. Ten countries were represented by delegates. The president and secretary of the S.U.N. committee attended the meeting, as well as H. Abraham

(general secretary of the I.P.U.), President Enström, and General Secretary LeMaistre of the I.E.C. At this meeting the actions taken at Oslo in regard to cgs magnetic units were endorsed unanimously.

In view of the many physicists assembling in Paris during the week July 5–12, 1932, to attend the 1932 Paris International Electrical Congress, the S.U.N. committee called an informal meeting in Paris on July 9, to discuss the matters contained in its questionnaire, and especially the cgs magnetic units. President Sir Richard Glazebrook was the chairman, and E. Griffiths was the secretary; 19 persons, from 8 countries, attended. The actions taken were informal, in the sense that the voting was by individuals and not by countries. The resolutions adopted, if not unanimous, were by considerable majorities. Among the resolutions was the proposition (6) "B and H are quantities of different nature." The Oslo convention was endorsed, and the I.E.C. actions concerning cgs magnetic units and their names, were confirmed. No specific reference was made to the Giorgi system; but it was voted that: "(1) Any system of units recommended must retain the 8 internationally recognized practical units: *joule, watt, coulomb, ampere, ohm, volt, farad, henry*." It was voted also that in any practical magnetic system, "the factor $4\pi/10$ should be retained in the definition of magnetomotive force." This implies that the S.U.N. committee opposed rationalizing the practical magnetic system.

At the Brussels meeting of the I.P.U. in July 1931, already mentioned, R. A. Millikan was elected as the incoming president, and it was contemplated holding the next I.P.U. meeting in Chicago, June 1933, contemporaneously with the Chicago exposition of 1933. It was found necessary, however, to postpone the I.P.U. meeting; but a meeting of the American Section of the I.P.U., with a few foreign guests, was held at Chicago instead, June 24, 1933, in Mandel Hall, University of Chicago. R. A. Millikan, president of the I.P.U., opened the meeting. The program was directed to the work of the international S.U.N. committee, and 6 papers were read, with E. C. Crittenden, chairman of the American S.U.N. committee in the chair. The papers[49] related to electric and magnetic units and systems, as prepared by R. T. Glazebrook, H. Abraham, L. Page, G. A. Campbell, H. L. Curtis, and A. E. Kennelly. E. Bennett acted as secretary of the meeting. The attendance at the meeting was about 150, and of these the estimated number voting was 30 to 40. In brief, the following resolutions[49–53] were passed:

1. That the classical cgs system should be left unchanged.

2. That the existing series of practical units may advantageously be extended into a complete absolute practical system, either through the mks system, or through the cg-ss system; of these, the mks system is preferred.

3. That the American S.U.N. committee shall be requested to consider the objections to the use of the absolute ohm and the advantage that might be gained by the use of the international ohm in the practical system.

A meeting of the E.M.M.U. committee of the I.E.C. was held[54] at Paris in October 1933. The *weber* was adopted as the practical unit of magnetic flux Φ, subject to the approval of the various national committees. The names *hertz* and *siemens* likewise were voted, for the names of the practical units of frequency and conductance, respectively. The Oslo convention concerning μ_0 and μ was reconfirmed. Special consideration was given to the resolutions passed by the American Section of the I.P.U. at Chicago in June 1933, on the extension of the practical series of units into a complete system, as referred to in preceding paragraphs. Giorgi, who was present as an Italian representative, gave a brief résumé of the mks system. H. Abraham, general secretary of the I.P.U., who attended the meeting, pointed out certain advantages of the mks system, as also did M. Brylinski, president of the French I.E.C. national committee. The following resolution was adopted unanimously:

"Section B of the advisory committee No. 1 on nomenclature, having heard with great interest the communication from Mr. Giorgi on the mks system, and endorsing the resolution adopted by the American Section of the International Union of Pure and Applied Physics at Chicago, in June 1933, decides to invite the national committees to give their opinion on the extension of the series of practical units at present employed in electrotechnics by its incorporation in a coherent system having as fundamental units of length, mass, and time, the meter, kilogram, and second, and as fourth unit either that of resistance expressed as the precise multiple 10^9 of cgs electromagnetic unit or the corresponding value of the space permeability of a vacuum."

These resolutions were distributed to all the I.E.C. national committees in the regular way, together with the minutes of the meeting, with a request for opinions.

Actions of the I.E.C. at the Latest and Plenary Meeting in Scheveningen-Brussels

In regard to actions on units, the E.M.M.U. committee met at Scheveningen, with representatives from 15 countries. President Enström attended the sessions. Paul Janet, president of advisory committee No. 1, was prevented from being present. He was unanimously elected honorary president of the I.E.C., an honor shared by Elihu Thomson. The principal actions taken at this meeting were briefly as follows:

1. The Oslo convention concerning μ_0 and μ was reconfirmed.

2. The adoption of the *weber* was confirmed as the name of the practical unit of magnetic flux Φ.

3. The replies were read as received from the various national committees concerning the extension of the practical series into a practical system of units, on the mks basis. Practically all the replies were in favor. The question of adopting the mks system then was moved and unanimously approved, except that 2 countries made reserves as to the suitability of retaining the *kilogram* as a basic unit of the system.

There was considerable difference of opinion among the delegates as to the fourth fundamental unit for the system. The *ohm* and the *coulomb* each had been suggested. It was agreed that a fourth unit was needed, because it would be possible, starting with the 3 units, meter, kilogram, and second, to construct an indefinite number of possible associated electromagnetic series, differing from the existing practical series which all desired to maintain. It finally was agreed to defer action on the choice of a fourth fundamental unit until an opportunity had been offered to consult the Comité Consultatif d'Electricité (C.C.E.) of the International Committee of Weights and Measures (I.C.W.M.) at Sèvres, and

also the S.U.N. committee of the I.P.U. In the meantime, it was voted that the new system should be called the "Giorgi System." Opinions also were requested from the various national committees as to the selection of the fourth unit.

4. By way of example, in the formation of derived units in the system, the following were adopted unanimously: (*a*) the volt per meter as unit of electric force; (*b*) the weber per square meter as unit of magnetic flux density B; (*c*) the joule per cubic meter as unit of volume energy.

5. The actions taken at the preceding meeting in Paris, concerning the practical unit names *hertz* and *siemens* were confirmed, as also the desirability of inserting the space permeability symbol μ_0 in all working magnetic formulas where its absence might mislead, thus reconfirming the Oslo convention.

Advantages of the Giorgi System to Students of Electrical Engineering

Table I, which gives a list of mks and cgs units, shows that although the classical cgs system in no way is altered or disturbed by the completion of the practical series into an independent practical system; yet:

1. There is great simplification in elimination of the necessity of learning the decimal ratios 10^9, 10^8, 10^7, 10^{-1}, and 10^{-9}, which connect various units in the 2 systems. The practical units all stand in unity-sequence relation.

2. The mks system is single and requires no accompanying companion electrostatic system. All electrostatic phenomena can be dealt with very easily through the existing electromagnetic practical units.

3. The dimensional formulas of the Giorgi units can be expressed without resorting to fractional exponents, as shown by Giorgi[55] and other writers.

4. It permits the use of either "rationalized" or "unrationalized" formulas, according to the choice of each writer, without disrupting the system on that account.

5. It requires no appreciable change in the existing literature and terminology of electric circuits. It may be said that the electrical engineering literature of the voltaic circuit is already Giorgian. It will not be difficult to transform the literature of the magnetic circuit from cgs to mks units.

6. For almost all practical purposes, the mks system can be studied and used now, without waiting for the formal adoption of the fourth fundamental unit to complete the system's base. Until readers become familiar with the expression of magnetic circuit formulas in mks units, the old cgs magnetic formulas may be retained in the cgs system without confusion.

7. It affords a clear perspective of the distinction between the earlier cgs units and the practical units, in regard to nomenclature and scope. If new cgs units be named, the names may conformably be impersonal. New practical units may conformably receive personal names, especially units 12, 13, and 16 in table I. If desired, a few impersonal names in the mks system might be changed later into personal names.

Comments

Table I shows that the only department of the cgs system in which personal names appear is that concerning the magnetic circuit. This discrepancy results from the resolution of the Chicago congress of 1893 to keep magnetic units out of the practical series. The very large aggregate number of electrotechnicians all over the world thus were impelled to seek for the magnetic circuit names they so earnestly desired, in the cgs system itself. Although this inconsistency is regrettable, it seems likely that with patience and good-will, it may be surmounted later.

Looking back upon the path of the development of units since 1861, when the B.A. made the first move in the direction of practical units, it appears that starting in about 1865 with the *ohm* and the *volt* based upon the cgs system, and with magnitudes selected fortuitously to suit the convenience of electric telegraphy, Ohm's law pointed the way from these 2 nuclei to the coherent magnitude of the *ampere* as the practical unit of current. These, in turn led, through other simple physical laws and their mathematical formulas, to the succeeding members of the practical series. After the *ohm* and *volt*, no further arbitrary choice was left, and the practical series determined itself. Each new member of the series made systematization more imperative and finally led to the completion of the whole series into the Giorgi system. It has been as though the marvelous simplicity of the physical universe in its individual actions, working on the minds of men engaged in physical applications, brought pressure upon them psychologically to imitate in their thoughts and arithmetic the order and system of the vast environment in the physical world. In 1935, the need for the system has reached the stage of international recognition, over a journey of 70 years. Under unfavorable conditions, the time required might have been much greater.

Table I also suggests the importance of co-operation among all scientific organizations, national as well as international, to maintain the systematic quality and classification of all units they employ. In a structure like the mks system there logically can be one and only one unit for each physical quantity.

In regard to the rationalization or nonrationalization of the mks system, discussions on the subject in recent years by the I.E.C. and I.P.U. committees have shown that there is much difference of opinion on the subject. In the E.M.M.U. committee, a small majority has been in favor of rationalization; in the S.U.N. committee, the majority has been more definitely against it. It is clear that any attempt to force a decision one way or the other at the present time would divide the mks adherents

Table II—Electric and Magnetic MKS Units Affected by the Deferred Question of Rationalization

No.	Quantity	Symbol	Name of Rationalized* MKS Unit	Unrationalized Units in One Rationalized Unit
Electrical				
49	Electric flux	ψ	coulomb	
50	Flux density	D	coulomb per square meter	
51	Space permittivity	ϵ_0	farad per meter	
52	Space elastivity	σ_0	meter per farad	
53	Elastance	S	daraf	
Magnetic				
54	Magnetomotive force	$\mathfrak{F}$ or M	ampere-turn	4π
55	Magnetizing force	H	ampere-turn per meter	4π
56	Space permeability	μ_0	henry per meter	$1/4\pi$
57	Space reluctivity	ν_0	meter per henry	4π
58	Permeance	$\mathcal{P}$	weber per ampere-turn	$1/4\pi$
59	Reluctance	$\mathcal{R}$	ampere-turn per weber	4π
60	Pole strength	m	weber	$1/4\pi$
61	Magnetic moment (ml)	$\mathfrak{M}$	weber-meter	$1/4\pi$
62	Magnetization	$\mathfrak{J}$	weber per square meter	$1/4\pi$

* No names have been chosen for unrationalized units.

Table III—Numerical Values of Space Constants in MKS System, Rationalized and Unrationalized

No.	Quantity	Symbol	Rationalized	Unrationalized
Electrical				
51	Permittivity	ϵ_0	$10^7/4\pi c^2 = 8.854 \times 10^{-12}$	$10^7/c^2 = 1.113 \times 10^{-10}$
52	Elastivity	σ_0	$4\pi c^2/10^7 = 1.129 \times 10^{11}$	$c^2/10^7 = 8.988 \times 10^9$
Magnetic				
56	Permeability	μ_0	$4\pi \times 10^{-7} = 1\,257 \times 10^{-6}$	10^{-7}
57	Reluctivity	ν_0	$10^7/4\pi = 0.7958 \times 10^6$	10^7

The value of the transmission velocity c is taken here as 2.998×10^8 meters per second and of c^2 as 8.988×10^{16} (meters per second)^2.

Because of admitted small discrepancies, of a few parts per myriad, between certain existing unit standards and their estimated absolute theoretical values, the future adoption of a fourth fundamental unit to complete the base of the mks system, might alter slightly some of the numerical "constants" in Table III.[55]

into 2 opposing camps, the rationalists and the nonrationalists. It seems desirable, therefore, to avoid the issue and to leave each writer free to follow his own choice, until experience may have crystallized opinion in the different countries. The same question pervades the cgs world today. The classical cgs electric and magnetic systems of Maxwell are unrationalized, while the Heaviside-Lorentz modification is rationalized. The advantages of rationalizing would be that the mks system thus would be made simpler, more logical, and coherent. There is much to be said for having pole strength identical with magnetic flux, so that a pole of one *weber* would give emergence to one *weber* of flux, and a charge of one *coulomb* also give emergence to one *coulomb* of electric flux. Table II shows that there are already enough practical international quantities to give names to all the principal units in the rationalized magnetic circuit, although some of them are cumbersome; whereas it appears to be necessary to adopt a series of new international names, in order to provide for the corresponding needs of the unrationalized circuit. Giorgi himself, in proposing his system (1901–04), rationalized it, as an act of recommendation. On the other hand, the disadvantage of rationalizing the mks system would be to break parallelism, in this direction, with the parent classical cgs system.

As regards the fundamental basis of the mks system, it has been pointed out by several writers that it is a blemish on the system to have (in the *kilo*gram) a basic *prefixed* unit. The mks *meter* is certainly preferable to the cgs *centimeter* in this respect; but the mks *kilogram* is inferior to the cgs *gram*. Theoretically, the basic units of any system should be prefix free. However, the cgs system has given splendid service to the world of science for many years, in spite of the *centimeter*.

Until there has been time to obtain the opinions of the I.C.W.M. and the I.P.U. on the question of choosing the fourth fundamental unit for the mks system, it would be invidious to offer any views on that point. It may be permissible to point out at this time, however, that whatever particular fourth unit may be selected in drawing up the international constitution of the Giorgi system, it is very desirable that each and all of the practical units in the ohm-volt-ampere series shall be identical for both basic and applied physicists. It surely would be a great misfortune to the whole scientific world if in taking up a standard ohm coil, or a standard capacitor, say 20 years hence, it should be necessary to ask whether it was standardized for physicists or electrotechnicians. Some trifling oversight in specifying the fourth fundamental unit might conceivably lead to such a divergence.

Further Developments

Since this paper was written in August 1935, the following important developments have occurred in relation to the Giorgi system:

1. The Consultative Committee on Electricity (C.C.E.) of the International Committee on Weights and Measures (I.C.W.M.) held meetings in Paris-Sèvres September 24–27, 1935, under the chairmanship of Paul Janet, and made an important report on electrical units and standards, covering also the reply to the I.E.C. inquiry concerning the fourth basic unit for the Giorgi system.

2. The I.C.W.M. held meetings in Paris-Sèvres, October 1–8, 1935, adopting this C.C.E. report and authorizing its general publication. It also issued a brief statement for publication concerning its own activities and aims.

3. The S.U.N. committee under Sir Richard Glazebrook has been actively engaged in securing opinions, by correspondence, as to the fourth basic unit in the Giorgi system for reply to the I.E.C. question on that point. The reply is expected to be published shortly.

Translations of the I.C.W.M. statement and of the C.C.E. report (from the original French texts) are given in Appendixes I and II.

Appendix I—Fourth Report of the Consultative Committee on Electricity (Comité Consultatif D'Electricité) to the International Committee of Weights and Measures

(As translated by the author from the original French text released for publication)

After notices sent out by the International Bureau of Weights and Measures, signed by President Paul Janet, the Consultative Committee on Electricity met in Paris, September 24–27, 1935.

At this fourth session of the committee, the following persons were in attendance:

Mr. Paul Janet, president, Membre de l'Institut de France, director of the Laboratoire Central d'Electriicté.
Mr. Crittenden of the National Bureau of Standards, Washington.
Mr. Sears of the National Physical Laboratory, Teddington.
Mr. Von Steinwehr of the Physikalisch-Technische Reichsanstalt, Berlin.
Mr. Nagaoka, professor emeritus of the University of Tokyo, representing the Electrotechnical Laboratory of Tokyo.
Mr. Lombardi, director of the Electrotechnical Laboratory of the Royal School of Engineers, Rome.
Mr. Guillaume, director of the International Bureau of Weights and Measures.
Mr. Jouaust of the Laboratoire Central d'Electricité, Paris.

In attendance by invitation were:

Mr. MacLellan, Member of the International Committee of Weights and Measures.
Mr. Vigoureux of the National Physical Laboratory.
Mr. Pérard, subdirector of the Bureau International des Poids et Mesures.
Messrs. Romanowski and Roux of the Bureau International des Poids et Mesures.
Mr. Brylinski, president of the French Committee of the I.E.C.
Mr. Kennelly, member of the International Committee of Weights and Measures, prevented from attending by ill health.

On opening the session, President Janet outlined the conditions under which the committee was convened:

The International Committtee, at its last meeting, decided on a recommendation from the Consultative Committee:

"That the Consultative Committee should request the laboratories it represents

to appoint members intended to form a technical subcommittee charged with the duty of making comparisons between their standards of resistance and voltage with all necessary precision, and to assign their values in terms of absolute units."

"That the technical subcommittee should meet at the International Bureau of Weights and Measures in 1935."

"That the decisions of the subcommittee should be examined by the Consultative Committee, before being transmitted to the International Committee."

In conformity with the above decision of the International Committee, Mr. Janet corresponded during the last 3 months of 1934 with the national laboratories represented on the Consultative Committee, requesting each to assign a member to the technical subcommittee, and to propose a date for the meeting of the subcommittee.

The majority of the replies showed that the tasks undertaken in the different laboratories for the determination in absolute units were not far enough advanced to permit of assigning to the regular laboratory standards their values in terms of the absolute system, that under these circumstances the work of the members of the technical subcommittee would be quite ineffective and would be limited to intercomparisons between the standards of the different laboratories, these intercomparisons being effected by conveyance between laboratories; these being either the national physical laboratories, or the International Bureau of Weights and Measures.

Under these conditions, Mr. Janet considered it necessary to postpone the meeting of the technical subcommittee, and to limit operations to a meeting of the Consultative Committee a few days in advance of the International Committee.

The object of the present meeting was therefore to examine the degree of progress in the determination of the absolute units, and the discussion of the precision of the methods employed; so that each member might profit from the experience of his colleagues.

The question of the realization of secondary standards presented itself, especially the nature of the metal to be employed for the construction of secondary standards of the ohm; also the question of the temperature to which they should be referred, might be considered.

In particular, Mr. Janet insisted upon the necessity for fixing at the present session, the date, if possible, for calling the meeting of the technical subcommittee and arranging its program. The fixing of this date was especially called for in a letter received from the Electrotechnical Laboratory of Tokyo.

Mr. Janet pointed out that he had also received information from Mr. Kennelly, that the International Electrotechnical Commission had adopted the mks system, called the Giorgi System, involving the establishment, in addition to the 3 classical fundamental units of length, mass, and time, a fourth fundamental unit, relating to an electrical magnitude, and that the Electrotechnical Commission desired to have the opinion of the Consultative Committee, as to the electrical magnitude which would be desirable to select for this unit.

Mr. Janet considered that, with certain reservations, this question might be placed on the agenda of the Consultative Committee. A report prepared by Mr. Lombardi, a member of the Consultative Committee and also of the International Electrotechnical Commission, might serve as the basis for discussion.

We may now summarize the results attained by the Consultative Committee:

I. Absolute Units

Only 2 laboratories have completed their tasks, namely, the National Bureau of Standards and the National Physical Laboratory, and only one of these investigations has taken the form of a complete publication; i. e., the determination of the ampere, made at the N.B.S. by Messrs. H. and R. Curtis.

The other laboratories (Physikalisch-Technische Reicheanstalt, Electrotechnical Laboratory, Laboratoire Central d'Electricité) have confined themselves to presenting certain notes on the methods employed. The representative of the Electrotechnical Laboratory, Mr. Nagaoka, announced that his establishment would shortly be able to report the result of its measurements. The representatives of the P.T.R. and L.C.E. have been unable to make any similar statement.

(*a*) *Absolute Value of the Unit of Resistance.* The National Bureau of Standards give the following result:

1 international ohm N.B.S. = 1.000 450 absolute ohm

The determination of the absolute ohm had been made at the National Physical Laboratory by 2 methods:

The Lorenz method gave:

1 international ohm N.P.L. = 1.000 50 ± 0.000 02 absolute ohm

By the Campbell method:

1 international ohm N.P.L. = 1.000 47 ± 0.000 02 absolute ohm

In the opinion of the representative of the N.P.L., in view of the precision of the 2 methods, it seemed desirable to take the mean of the 2 above values, and to take as the N.P.L. result:

1 international ohm N.P.L. = 1.000 49 absolute ohm

The above are the only results definitely communicated to the Consultative Committee. The difference of the order of a few millionths between the international N.P.L. ohm and the international N.B.S. ohm, make these results directly comparable.

Moreover, the representative of the Physikalisch-Technische Reichsanstalt observed that certain corrections should be applied to the old measurements of Grueneisen and Giebe, which would lead to the following:

1 international ohm P.T.R. = 1.000 49 absolute ohm

All the above results seem to indicate that one may hope for a knowledge of the ratio of the international ohm to the absolute ohm, when all the laboratories shall have finished their task, to a precision of $\pm 2 \times 10^{-5}$.

(*b*) *Absolute Value of the Unit of Current Strength.* Only 2 laboratories, the N.B.S. and the N.P.L. have finished their researches. The results obtained, expressed in the form used in the reports to the Committee are:

Bureau of Standards

1 international ampere N.B.S. = 0.999 926 absolute ampere

National Physical Laboratory

1 absolute ampere = 1.000 14 international ampere N.P.L.

If account is taken of the difference which exists in the realization of the international ampere in the 2 laboratories, these 2 results differ by 9 hundred-thousandths.

The agreement in the determination of the unit of current strength is thus much less close than in the determination of the unit of resistance.

Discussion of the methods of measurement employed led to an interesting remark from the representative of the P.T.R., on the difficulty of calculating, for the Balance of Lord Rayleigh, the correction due to the volume of the bobbin windings. He observed that in the work of H. and R. Curtis, it was possible to arrive at 2 different values for this correction, according to the method used in measuring the windings.

Reference was made to a recent work of Sir Richard Glazebrook, recently appearing in the *Proceedings* of the Royal Society, *A*, volume 150, 1935, page 487, setting forth the same difficulty.

Mr. Von Steinwehr also mentioned that in order to remedy this difficulty, the Reichsanstalt had given up the method of winding the coils of the Rayleigh balance with wire, in favor of a method of band winding. The necessity of redetermining the radii ratio for these new coils, was one of the reasons for the Reichsanstalt not yet being ready to furnish results.

Mr. Crittenden recognized the importance of Mr. Von Steinwehr's remark, and indicated that at the N.B.S. they had undertaken in their Rayleigh type of electro-dynamometer, the construction of new coils, one made with bands, and the other with but a single layer of wire.

In any case, it would seem that this uncertainty as to a correction does not completely explain the difference between the N.B.S. and the N.P.L.

The committee, while expressing its regrets for the technical difficulties that had hindered the completion of its undertaking, felt glad that the meeting had given rise to a suggestive discussion for all who are engaged in the determination of units to absolute measure.

II. Present Representation of the Units

The value of the international ohm is maintained in the laboratories by means of manganin coils. The resistance of these coils is not constant, but varies slowly as a function of time.

Is it possible to find for the construction of these coils, a metal free from such variations?

A report from the National Physical Laboratory, presented and commented on by Mr. Vigoureux, described the experiments made

n that establishment, for the production of ohm standards in platinum.

Having given the value of the temperature coefficient of resistivity or platinum, these resistances should be used at a practically well determined temperature, that of melting ice.

Mr. Pérard drew the committee's attention to the difficulty which may exist in keeping such resistances precisely at the temperature of melting ice. Mr. Von Steinwehr alluded to the use of the "triple point."

However that may be, many years must elapse before one can be assured of the constancy of these resistances.

The Committee could therefore only felicitate the National Physical Laboratory upon the undertaking of this research.

Questions were asked of the representative of the National Bureau of Standards concerning a new alloy studied in that establishment. Mr. Von Steinwehr remarked that studies had also been made at the P.T.R. on this chromium-gold alloy, and that it had been possible to obtain specimens whose temperature coefficient between 20 and 30 degrees centigrade was almost zero.

But there is still no assurance as to the stability of this alloy, so that it will still be necessary for a long time to come, to construct secondary ohm standards in manganin.

The committee listened also with interest to the account given by Mr. Vigoureux of the method employed at the N.P.L. in the search for standards having a resistance as nearly constant as possible.

A considerable part of the variations manifested by these resistances is attributed to the layer of lacquer which covers them.

At the N.P.L., the manganin wire, rolled under the form which it will occupy on its supporting core, is annealed at 500 degrees, treated with acid, and then placed on its supporting core without being subjected to any mechanical deformation. The layer of lacquer which is intended to protect the wire against the action of the petroleum bath in which it is submerged, is made as thin as possible.

III. Comparison of the Standards From Different Laboratories

Mr. Pérard drew direct attention to the fact that the reference temperature of the units should be standardized. In European countries, this temperature is 20 degrees centigrade; but in the United States and Japan, it is 25 degrees centigrade.

Mr. Pérard requested that this temperature should be fixed, and proposed 20 degrees centigrade.

Mr. Crittenden (United States), and Mr. Nagaoka (Japan), pointed out that in their countries, the temperature was close to 25 degrees centigrade. They indicated the difficulty there would be in keeping the standards at a temperature lower than the ambient temperature. Nevertheless they agreed to the temperature of 20 degrees centigrade for standards intended for international comparison.

This agreement was recorded in a resolution. (See appended Resolution 1, at the end of the report.)

The transport of standards from one laboratory to another, involves certain difficulties.

In a note sent to the committee, the Electrotechnical Laboratory of Tokyo described the boxes which it utilized for the transport of standard cells.

Certain laboratory representatives pointed out, however, the difficulties that customhouse administrations had given them, and asked whether it would not be possible to use the consular bag (*valise diplomatique*) for standards intended for international comparison.

It was decided to ask the president of the International Committee of Weights and Measures to take the steps necessary for having standards intended for international comparison accepted for transport in consular bags (Resolution 2).

Messrs. Pérard, Romanowski, and Roux reported on comparisons made at the International Bureau of Weights and Measures, of standards of resistance and of electromotive force from laboratories represented in the membership of the Committee.

The results were rendered comparable by taking for the mean value of the units, the arithmetical mean of the units in the 6 laboratories, and by indicating the difference between the unit of each laboratory and this mean.

The representative of the Laboratoire Central, Mr. Jouaust, stated that the units of the establishment to which he belonged differed the most, particularly as regards the mean value of the resistance units.

The cause of these divergences of 7 hundred-thousandths had not, of course, escaped him. In view of accidental error, he asserted that the Laboratoire Central intends to modify the value of its standards, so as to bring them into agreement with those of the other 5 laboratories.

By employing only these 5 values, in the establishment of the average, the difference between the resistance units of these laboratories and their average would then appear as follows (at the date of March 15, 1935):

P.T.R.	+ 9.8 millionths
N.B.S.	− 5.5 millionths
N.P.L.	− 3.6 millionths
E.T.L.	−11.2 millionths
U.R.S.S.	+10.6 millionths

The above differences are small; but nevertheless it may be necessary to take them into account in certain cases. In consequence, Mr. Jouaust asked if the different laboratories could not follow the example set by the Laboratoire Central and modify the value of their unit for the purpose of standardization.

This proposition met with some opposition. The values of the units being due to be changed shortly, to be expressed in absolute units, certain members of the committee considered that it would be preferable to await that date before proceeding to the proposed standardization.

Others did not consider themselves authorized to accept any change in a standard of their country, however small.

Nevertheless, the Committee concluded by adopting resolution 4.

IV. Fixing the Date of Meeting for the Technical Subcommittee

President Janet renewed attention to the agreement arrived at on this matter by the Consultative Committee at its last session.

He insisted on the necessity of fixing this date for the subcommittee, pointing out that Japan proposed that this date should be set between June and December 1936. He also asked the committee to specify the duties to be assigned to the subcommittee.

All the members agreed that the 2 parts of the program indicated for the subcommittee still hold, and that the comparisons appearing in its program were only set up for the purpose of immediately fixing the values in absolute units.

The 2 functions of the subcommittee are inseparable.

It was unanimously agreed that it would only be possible to convene the subcommittee after a sufficient lapse of time to enable its members to carry out the comparisons themselves. Only certain ones could be effected. The principal task of the subcommittee will therefore be to discuss the values found and assign weights to them.

The setting of the date for the subcommittee gave rise to some remarks from Mr. Von Steinwehr, who wished to leave the date to the president with power to fix it when he judged the work of the laboratories was sufficiently far advanced. It was finally decided to set the date at the beginning of the year 1937 (Resolution 3).

V. Examination of the Question Raised by the International Electrotechnical Commission Relative to the MKS System

In opening the meeting, President Janet explained the conditions under which the matter was laid before the Consultative Committee.

The Consultative Committee was appointed to inform the International Committee of Weights and Measures on questions relating to standards in the electrical field and in adjacent subjects.

In giving advice to any other organization, it would be going outside the limits assigned to it.

The International Electrotechnical Commission should therefore have addressed its question to the International Committee.

But it is almost self evident that the International Committee would wish to have the opinion of the Consultative Committee. But since the session of the latter preceded that of the International Committee, if the question had been transmitted directly to the International Committee, it would have been impossible to bring it before the Consulting Committee without a rather long delay.

Under these conditions, with the approval of Mr. Volterra, president of the International Committee, Mr. Janet considered himself justified in placing the matter on the agenda of the Consultative Committee, it being understood that any opinion reached would be forwarded to the International Committee, which is alone competent to reply. The president asked the members of the Consultative Committee if they approved of the procedure he suggested.

This procedure was unanimously adopted.

On the other hand, the Consultative Committee forwarded to the International Committee a series of proposals anonymously received,

relating to questions of notation and nomenclature. The Committee then proceeded to an examination of the question presented by the I.E.C.

The question is set forth in a communication from Mr. Lombardi. Moreover, the members of the Committee were in possession of various documents on the subject, emanating from Sir Richard Glazebrook and from Messrs. Kennelly, Campbell, Giorgi, Emde, Wallot, and Bennett.

Mr. Lombardi presented his memoir with comments. From this presentation, it appears that the original form of the mks system, as given by Mr. Giorgi and strongly endorsed by Mr. Campbell, should comprise 4 fundamental units of which only 3, the meter, the kilogram, and the second were originally indicated. The fourth should now be fixed in such a manner as to permit of incorporation into a coherent system the well-known practical units of current, electric quantity, electromotive force, capacitance, resistance, inductance, and magnetic flux. Messrs. Giorgi and Campbell have proposed the international ohm for the fourth unit, in view of the large number of its existing standards; but their proposal could not be entertained by the International Electrotechnical Commission after the decision by the International Commission of Weights and Measures, ratified by the General Conference of 1933, to substitute the absolute system for the international system.

The I.E.C. did not consider that it could adopt the permeability of space unchanged since it has not the essential character of a unit and is not susceptible of being embodied in a standard, but assumes different values in the rationalized and nonrationalized mks system between which no definite choice has yet been made, by international agreement. For this reason the I.E.C. considered that the choice should be limited to the 7 practical units above referred to, which from a theoretical standpoint are equivalent in this regard, and which being dependent on the absolute cgs system are necessarily related to the unity value of space permeability. With reference to the ease of construction and comparison of standards, Mr. Lombardi has shown in his paper some preference for the unit of resistance without losing sight of the fact that certain among the other units might possess similar advantages, and that the creation of a primary standard could only be effected to an approximation quite sufficient for practice without possessing the absolute invariability attributable to the other fundamental units of length, mass, and time selected arbitrarily and represented to some extent conventionally by concrete standards maintained at Breteuil.

Mr. Janet drew the attention of the committee to the opinion of Sir Richard Glazebrook, president of the S.U.N. commission, definitely expressing the opinion that the fourth unit should be the magnetic permeability of vacuum, to which in the mks system would be given the value 10^{-7}; so that the electrical units of the mks system would be the practical units of the absolute system. He also read a letter from Sir Joseph Petavel, stating that the executive committee of the National Physical Laboratory supported this proposal.

Mr. Sears observed that in making a selection of a fourth unit at the request of the I.E.C., the committee accepted by implication the mks system, so far as concerns the electrical units. But the mks system is essentially the same as the cgs system, there being only a difference of powers of 10.

Therefore the committee should not assign any superiority of choice, and should manifest no preference.

By a large majority, the committee decided for a selection of the permeability of space. Mr. Nagaoka, representing Japan, abstained, and Mr. Crittenden stated that his opinion was a personal one.

On the observation by Mr. Lombardi, that the solution indicated by the committee was aside from that sought by the I.E.C., and that the committee should only select from among the 7 units already referred to, the president consulted the committee anew under the following form: If the solution of fixing the value of space permeability were set aside, which electrical unit would you propose to introduce for definition into the mks system?

By the feeble majority of 4 votes against 3 and 1 abstention, the committee declared for the ohm, after a protest from one of the members at the limitation imposed on the opinion asked for, in the form of the question raised by the I.E.C., and finally a draft opinion drawn up by Messrs. Pérard and Jouaust, appearing at the end of the present report, was approved by the committee. (Resolution 5*a*.)

The day after the above discussion, Mr. Sears read a note which he had drawn up. To a question from one of the members, he explained that the values given in paragraph 5 below only represent an ideal series of derived units from among a number of possibilities, and that this plan should not be taken as definitely assigning the procedure to be followed in the practical development of standards.

He showed by way of example, the possibility of deriving, practically, all of the electrical units from the construction of an inductance.

The proposals of Mr. Sears, which are not in opposition to the preceding decisions of the committee, were much appreciated by the members, who expressed the opinion that Mr. Sears's note, whose text is appended (Resolution 5*b*) should be transmitted to the International Committee, along with the opinions previously expressed.

VI. Visits

The members of the committee were invited by Mr. Janet to visit the rooms of the Laboratoire Central d'Electricité, where researches are made on electrical units, and to examine the apparatus in course of construction for the determination of the ohm in absolute measure.

Before concluding, the committee voted its thanks to Mr. Janet for the manner in which he had directed the discussions, and to Mr. Perard for his care in securing the successful operation of the sessions, and especially for assuring the advance distribution of the documents needed in the committee's work. Mr. Jouaust, of the Laboratoire Central d'Electricité, was appointed secretary for the session of 1935.

Resolutions Voted by the Consultative Committee on Electricity in Its Session of September 1935

Resolution 1. For international comparison of electrical standards, the values reported will be those corresponding to a temperature of 20 degrees centigrade, unless an exception is justified.

Resolution 2. The Consultative Committee requests the International Committee to pass a resolution, which should be transmitted to the interested governments, to the end that delicate instruments, and especially electrical standards, may be transported through the medium of the consular bag, (*valise diplomatique*), so as to avoid opening at customhouses, full liberty being, however, allowed to those laboratories that may prefer some other mode of conveyance.

Resolution 3. The Consultative Committee decides to fix at first the meeting of the technical subcommittee at the beginning of the year 1937. The Consultative Committee will then meet in the course of that year, a few days before the regular session of the International Committee of Weights and Measures.

Resolution 4. The Consultative Committee on Electricity records with satisfaction the decision taken by the Laboratoire Central d'Electricité, to modify forthwith the magnitude of its unit of electrical resistance, as well as that of its unit of electromotive force, by some few hundred-thousandths, in order to bring them into agreement respectively with the corresponding averages of the values for these units as they are maintained in the 5 other great national laboratories: The Physikalisch Technische Reichsanstalt, the National Physical Laboratory, the National Bureau of Standards, the Electrotechnical Laboratory of Tokyo, and the Metrological Institute of the U.R.S.S.

The Consultative Committee: Considering in that case how very small would be the deviations of the ohm unit and volt unit in each of the 5 laboratories from the respective averages above mentioned, the greatest deviation for either the ohm or volt scarcely reaching 11 millionths; and considering the great importance which would be presented by unification of electrical units in the near future in all countries; suggests to the different laboratories, each acting for itself, and as soon as an opportunity may be offered, to adopt for the magnitude of the ohm and for the magnitude of the volt, respectively, the values defined by the above-mentioned averages.

Resolution 5a. The Consultative Committee on Electricity, upon a question from the International Electrotechnical Commission, relating to the most suitable choice of an electric unit in the mks system, desires first to observe, that according to the Rules of its Constitution, it can only communicate with the International Committee of Weights and Measures. Nevertheless, with the consent of the president of the International Committee, it decided to consider the question presented, the opinion reached being reported to that committee, which alone is competent to make reply.

The Consultative Committee first desires to state that a distinct majority of its members present expressed the opinion that the link between the mechanical and electrical units should be effected by

assigning the value 10^{-7} in an unrationalized mks system, and $4\pi \cdot 10^{-7}$ in a rationalized system, to what is commonly called the permeability of space.

As to the remark that the form in which the question was put limited the choice to the 7 practical units, coulomb, ampere, volt, ohm, henry, farad and weber, the committee unanimously considered that the choice should only fall either on the ampere, defined as 10^{-1} of the cgs electromagnetic unit, or on the ohm, defined as 10^9 cgs electromagnetic units of resistance, these 2 magnitudes, corresponding to the values of 10^{-7} or $4\pi \cdot 10^{-7}$ for space permeability, as above mentioned.

By vote, the committee pronounced in favor of the ohm against the ampere by the small majority of 4 against 3, and 1 abstention.

Resolution 5b. In the following session, Mr. Sears presented to the Consultative Committee the following document:*

Note presented by Mr. Sears:

1. The electrical unit magnitudes of the system sanctioned by the General Conference in 1933, are identical with those of the practical units derived from the classical cgs system of Maxwell.

2. These systems are based essentially on the conception of a constant value for space permeability, this value being in the Maxwell system numerically equal to 1. For the mks system unrationalized, this permeability would have the value 10^{-7}, and for the mks system rationalized, the value $4\pi \cdot 10^{-7}$. In each of these systems the coefficient A^* is taken as a purely numerical constant, to which is assigned the value unity so that it no longer appears in the equations. The principal units of the 2 mks systems would thus be the same as those of the practical system, the adoption of which was sanctioned by the General Conference of 1933.

3. The various electrical units can all be derived from this conception, by means of equations representing physical laws, and with suitably selected constants. In principle, no one of these units has priority over the rest.

4. The definitions adopted for the principal electromagnetic units might be the following:

(a) *Ampere.* The ampere is the constant current which, maintained in 2 parallel rectilinear conductors of infinite length, separated by a distance of 1 meter, produces between these conductors a force equal to 2×10^{-7} mks units of force per meter of length.

(b) *Coulomb.* The coulomb is the quantity of electricity transported each second by a current of one ampere.

(c) *Volt.* The volt is the difference of electrical potential between 2 points of a conducting wire carrying a constant current of one ampere, when the power dissipated between these points is equal to one mks unit of power (watt).

(d) *Ohm.* The ohm is the electrical resistance between 2 points of a conductor, when a constant difference of potential of one volt, applied between these points, produces in the conductor a current of one ampere, the conductor not being the seat of an electromotive force.

(e) *Weber.* The weber is the magnetic flux which, traversing a circuit of a single turn, would produce an electromotive force of one volt, if brought to zero in one second with uniform diminution.

(f) *Henry.* The henry is the inductance of a closed circuit in which an electromotive force of one volt is produced when the electric current traversing the circuit varies uniformly at the rate of one ampere per second.

(g) *Farad.* The farad is the electrical capacitance of a capacitor between the armatures of which appears an electrical difference of potential of one volt, when charged with one coulomb of electric quantity.

5. These units may be derived as follows:

Ampere	I	Ampere	I
Coulomb	Q	Ampere-second	IT
Volt	E	Watt per ampere	PI^{-1}
Ohm	R	Volt per ampere	EI^{-1}
Weber		Volt-second	ET
Henry	L	Volt-second per ampere	$EI^{-1}T$
Farad	C	Ampere-second per volt	$E^{-1}IT$

* In the course of the meetings of the International Committee of Weights and Measures, Mr. Sears asked permission to insert certain additions at the head of this note in conformity with suggestions made to him by Sir Richard Glazebrook, these additions not affecting the general meaning of the note. The following paragraph has therefore been added:

Electromagnetic theory leads to the relation

$$A^2 \equiv \mu_0 \times k_0 \times c^2$$

between the 4 quantities there appearing. Of these,
c is the velocity of the propagation of electromagnetic waves in vacuum
μ_0 is the magnetic permeability of a vacuum
k_0 is the permittivity of a vacuum
A is a constant coefficient
In order to have a theoretically complete system of electrical units, it is necessary to assign independent values to 2 of the 3 quantities A, μ_0, and k_0. The third will then be determined by the above relation. In each of these systems the coefficient A is taken as a purely numerical constant to which is assigned the value given above so that it no longer appears in the equations. The principal units of the 2 mks systems would thus be the same as those of the practical system, the adoption of which was sanctioned by the general conference of 1933.

6. For the regular practice of laboratory measurements, at least 2 primary standards of reference are needed and may be conveniently chosen among the various units. The 2 reference standards should be the ohm and volt, the former being produced under the form of coils and the latter under the form of Weston cells.

7. For theoretical questions, such as the dimensional equations connecting the various units, the most convenient unit as a starting point for the derivation of the entire system of electromagnetic units appears to be the ampere, which is directly connected by simple relations not only with the fundamental base of the system; but also with the other electric and magnetic magnitudes, and which, moreover, has the advantage of eliminating fractional powers from the dimensional equations. In this respect, the ampere should be preferred as the fourth unit, in order to complete the mks system of electromagnetic units.

This document met with a unanimously favorable reception in the Consultative Committee, which decided to transmit it to the International Committee without, however, finding it necessary to alter its vote of the previous day.

Appendix II—Intended Substitution of the Practical Absolute System of Electrical Units for the Existing International System

The following information (as translated from the original French text) was approved for general publication by the International Committee of Weights and Measures at its meeting in October 1935, at Sevres, France.

1. In accordance with the authority and responsibility placed upon it by the General Conference of Weights and Measures in 1933, the International Committee of Weights and Measures has decided that the actual substitution of the absolute system of electrical units for the international system shall take place on January 1, 1940.

2. In collaboration with the national physical laboratories, the committee is actively engaged in establishing the ratios between the international units and the corresponding practical absolute units.

3. The committee directs attention to the fact that it is not at all necessary for any existing electrical standard to be altered or modified with a view to making its actual value conform with the new units. For the majority of engineering applications, the old values of the international standards will be sufficiently close to the new for no change, even of a numerical nature, to be required. If for any special reason a higher precision is necessary, numerical corrections can always be applied.

4. The following table gives a provisional list of the ratios of the international units to the corresponding practical absolute units, taken to the fourth decimal place. Since differences affecting the fifth decimal place exist between the standards of the international units held by the various national laboratories and also because all the laboratories which have undertaken determinations of the values of their standards in absolute measure have not yet obtained final results, the committee does not consider it desirable for the present to seek a higher precision. At the same time, it hopes that it will be possible to extend the table of these ratios, with a close approximation to the fifth decimal place, well before the date fixed for the actual substitution of the practical absolute system for the international system.

Table

1	Ampere	international	=	0.999 9	Ampere	absolute
1	Coulomb	international	=	0.999 9	Coulomb	absolute
1	Ohm	international	=	1.000 5	Ohm	absolute
1	Volt	international	=	1.000 4	Volt	absolute
1	Henry	international	=	1.000 5	Henry	absolute
1	Farad	international	=	0.999 5	Farad	absolute
1	Weber	international	=	1.000 4	Weber	absolute
1	Watt	international	=	1.000 3	Watt	absolute
1	Joule	international	=	1.000 3	Joule	absolute

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Pull-In Characteristics of Synchronous Motors

The differential analyzer has proved its worth in solving various types of difficult problems, of which the determination of the pull-in characteristics of salient pole synchronous motors is typical; but even with the aid of this device it has been necessary in solving this problem to make several simplifying assumptions. The differential analyzer recently completed at the University of Pennsylvania, however, is sufficiently comprehensive in design so that few assumptions are necessary, and the major electrical transients and mechanical forces may be taken into account. Typical solutions obtained by means of this analyzer are presented herewith, together with practical pulling-into-step criteria.

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CONSIDERABLE attention has been devoted in recent years to the problem of pulling synchronous motors into step. The difficulties involved in the solution of this problem by past available means have necessitated several simplifying assumptions which have severely limited the application of the results. The recent completion of a large differential analyzer at the University of Pennsylvania has made it possible, for the first time to the authors' knowledge, to obtain solutions of the phenomena of pulling into step, taking into account the major electrical transients and mechanical forces. Typical solutions given by this differential analyzer are presented in this paper, together with practical criteria for predetermining with engineering accuracy whether a given motor will or will not pull into step under specified conditions. The important points brought out in the paper are briefly:

1. A method is outlined whereby specific solutions of the pull-in problem, and similar problems involving the balanced 3 phase characteristics of a machine near synchronism (i. e., synchronizing out of phase, stability, hunting, etc.) may be secured accurately through the use of the differential analyzer.

2. Consideration of the synchronizing performance of motors must be based upon the electrical as well as the mechanical transients.

3. Motors with long time constants are sensitive to the angle of application of excitation, the most favorable angle being that where the field flux linkages are at a positive maximum. This corresponds with the point at which the field current crósses the zero axis, increasing in the positive direction.

4. The pull-in characteristic of a motor when excitation is applied at the most favorable angle is determined largely by the field flux linkages existing at that instant.

5. The average slip from which the motor must pull into step when excitation is applied under the most unfavorable conditions is determined by the net average torque available with the field fully excited and the motor operating out of synchronism.

6. The pull-in performance of motors for the most favorable and unfavorable angles at which the field excitation may be applied, can be calculated with a reasonable degree of accuracy by use of the criteria presented herein.

Nature of Past Investigations

In attacking this problem, other investigators[9,10] have assumed that the synchronous motor might be considered as 2 electrically independent machines: one developing only synchronous and reluctance torques without electrical transients other than that represented by an exponential rate of increase of synchronous torque; the other, an induction motor developing torque as a function of slip and angle. The effect of armature circuit resistance has been neglected, as has also the effect of rate of change of slip upon electrical torque. These investigations resulted in the establishment of empirical factors which were checked by laboratory tests on relatively small machines.

Predictions based upon these factors indicate that the angle at which excitation is applied should make no material difference in the pulling into step performance of a synchronous motor having a long time constant. In actual practice it has been found that the performance of such motors is influenced materially by the angle of application of the excitation.[12]

Approximately 3 years ago, in studying this problem, it was concluded that the synchronous and induction motor components of torque could not be separated entirely, and that it was of importance, in considering the synchronous component of torque, to determine the field linkages at the time the excitation was applied, and not merely assume that the synchronous component built up exponentially from zero. A few step-by-step swing curves were made, taking into account the electrical transients. These calculations indicated that it was, indeed, necessary to consider the linkages in the field circuit that were present at the time of applying excitation. The step-by-step method was so laborious, however, that, beyond proving the importance of considering the major electrical transients, little progress could be made. The nature of the problem was so involved

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9. For all numbered references see list at end of paper.

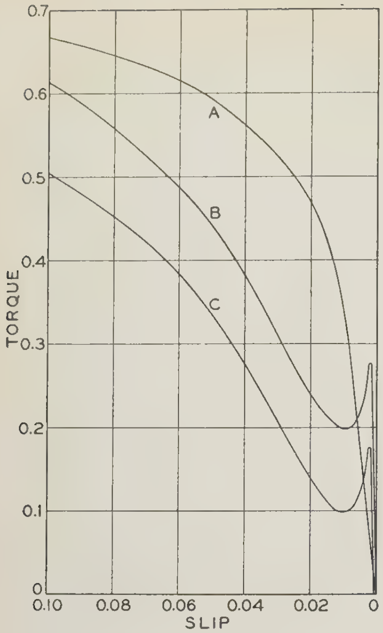


Fig. 1. Average induction motor torque for speeds higher than 90 per cent synchronous speed

Curve *A*—With discharge resistance 8.5 times field resistance

Curve *B*—With field short-circuited

Curve C—With rated field excitation

that the differential analyzers then available could not be used for its solution.

Curve *A* of figure 1 shows the induction motor torque-slip curve of a typical machine for the region near synchronism. It indicates that the relationship between slip and torque is approximately linear at speeds greater than 98 per cent synchronous speed, but departs materially from this for greater values of slip. An examination of curve *B* indicates that it is necessary to consider the modification in the induction motor torque once the discharge resistor is removed from the field circuit. This subject has been discussed in previous literature and needs no further explanation here.[13] The important point is that if the motor does not pull into step immediately but slips several poles, the induction motor torque will be considerably less than that previously developed by the motor with the discharge resistor in the circuit. This will result in an increase in average slip. A third effect is indicated by curve *C* which shows the net average torque developed when the motor is operating at a constant slip with full field excitation. The reduction in torque from curve *B* to curve *C* is caused by the losses in the armature circuit resistance resulting from the applied excitation.

In making the step-by-step calculations it was noted that the induction motor performance was modified when there was a relatively high rate of change of slip. This characteristic has been observed in induction motors that were accelerated on full voltage, without retarding intertia (WR^2) or load, with a rate of acceleration such that the speed of the machines momentarily exceeded synchronous speed. The duration of the electrical transients was greater than the time required for the motor to pass from, say, 5 per cent to zero slip, thus producing a persistence of motor torque above synchronous speed for a short period of time. Identical phenomena were observed in some of the solutions obtained by use of the differential analyzer.

Purpose and Scope of Present Investigation

The purpose of this investigation is to develop and present the results of a more general approach to the synchronizing problem than heretofore has been available. Because of the number of variables involved in such an approach, a tremendous number of solutions would be required to determine families of curves giving the exact characteristics of all synchronous machines. Accordingly, such solutions were secured for particular machines as would provide a basis for the development of suitable criteria for synchronizing under favorable and unfavorable conditions. These solutions encompassed variations in load torque, inertia, excitation, and angle of applying excitation.

Method of Using a Differential Analyzer in Solving the Pull-In Problem

The method of solution was based upon the generalized 2 reaction theory of synchronous machine performance, using equations presented by Park,[4] with such modifications as were expedient to put them in a form suitable for solution by means of the analyzer. The equations, as given in appendix I, are:

$$e \sin \delta = p\psi_d - ri_d - \psi_q - \psi_q \frac{d\delta}{dt} \tag{1}$$

$$e \cos \delta = p\psi_q - ri_q + \psi_d + \psi_d \frac{d\delta}{dt} \tag{2}$$

$$\psi_d = -x_d i_d + \psi_{d1} + \psi_{d2} \tag{9}$$

$$\psi_{d1} = x_d A_{d1} i_d - \alpha_{d1} \int (\psi_{d1} - x_d B_{d1} E_{fd} 1) dt \tag{12}$$

$$\psi_{d2} = x_d A_{d2} i_d - \alpha_{d2} \int (\psi_{d2} - x_d B_{d2} E_{fd} 1) dt \tag{13}$$

$$\psi_q = -x_q'' i_q - x_q \alpha_{q1} \int i_q dt - \alpha_{q1} \int \psi_q dt \tag{22}$$

$$4\pi f H \frac{d\delta}{dt} = -T_L t - \int i_q \psi_d dt + \int i_d \psi_q dt \tag{23}$$

These equations include the effect of armature circuit resistance. Their use assumes that the machine is "ideal" as defined by Park,[4] and that the amortisseur winding can be represented with reasonable accuracy by one short-circuited winding in the direct axis and one in the quadrature axis.

The analyzer was arranged to secure the simultaneous solution of these equations. The set-up is shown in simplified diagrammatic form in figure 2. All factors such as scales, signs, and certain mechanical considerations involved in forcing the solution of the numerous simultaneous equations are omitted from this diagram. It is believed that a complete description of the functioning of the analyzer in solving these equations is unnecessary here as the subject has been covered adequately in previous literature.[8,10,11] It may be well, however, to call attention to several specific features.

The multipliers, which are inherently capable of less accuracy than the integrators, were used only in securing the quantities $\psi_q(d\delta/dt)$ and $\psi_d(d\delta/dt)$, which are small near synchronism.

An interesting feature of the set-up is that in-

volving the quantities $p\psi_d$ and $p\psi_q$, which were secured through the use of 2 integrators. Operators stationed at each of these integrators introduced $p\psi_d$ and $p\psi_q$ into the machine solution. These quantities then were integrated and, when the operators were introducing them correctly into the equations, their integrals were equal to ψ_d and ψ_q, respectively. Comparisons of these equalities were made by means of 2 differential gear units, or adders. The third element of each of the adders merely indicated whether the 2 quantities introduced into the the adder were equal in magnitude and of proper sign. The operators then manipulated the cranks in such a manner that the indicating elements of the adders remained stationary and thus correctly generated $p\psi_d$ and $p\psi_q$. The accuracy of this method may be subject to some question, but here again the quantities introduced were small near synchronism so that errors in them had an insignificant effect on the solution.

Excitation voltage was introduced into the solutions, as a unit function, by adding the quantities $x_dB_{d1}E_{fd}\mathbf{1}$ and $x_dB_{d2}E_{fd}\mathbf{1}$ to the integrands of equations 12 and 13, respectively. At the same time, gear trains were modified to take account of the change in machine constants necessitated by the reduction in field circuit resistance.

It is of interest to note that the free quantity in each equation corresponds to a dependent variable in the actual synchronous machine performance; that is, in equations 1 and 2 all quantities except ψ_d and ψ_q actually are driven either from integrator units, the time motor, or cranks turned by the machine operators.

In equations 9, 12, and 13, the free quantity is i_d, assuming here that ψ_d is driven from equation 2. In a similar manner ψ_q results from equation 1 and i_q from equation 22. Thus, the quantities determined by the foregoing equations are primarily the direct and quadrature axis armature linkages and the corresponding currents. These are used in equation 23 in determining the electrical torque, which, together with an assumed constant load torque, determines the slip, $d\delta/dt$. Integration of this quantity gives the angle δ which in turn is used on the input tables in determining, by the sine and cosine curves, the voltage applied to each axis.

The equations as derived and placed upon the machine take account of armature circuit resistance, a factor that seldom is considered correctly in machine calculations under transient conditions, because of the difficulties involved. Should it be desired to neglect the effect of armature circuit resistance, considerable simplification in analyzer operation may be made. Under this condition $e \sin \delta = -\psi_q$ and $e \cos \delta = \psi_d$, and, accordingly, the operation of 2 integrators and the 2 multipliers will not be required. A few solutions were obtained in this manner to determine whether the amount of resistance included introduced an appreciable effect. When it was found that such was the case, all further solutions were made, including the effect of normal values of armature circuit resistance.

The correctness and accuracy of the solutions obtained were checked in several ways. The average values of slip obtained, on runs corresponding to induction motor operation, agreed closely with the values of slip calculated in the conventional manner

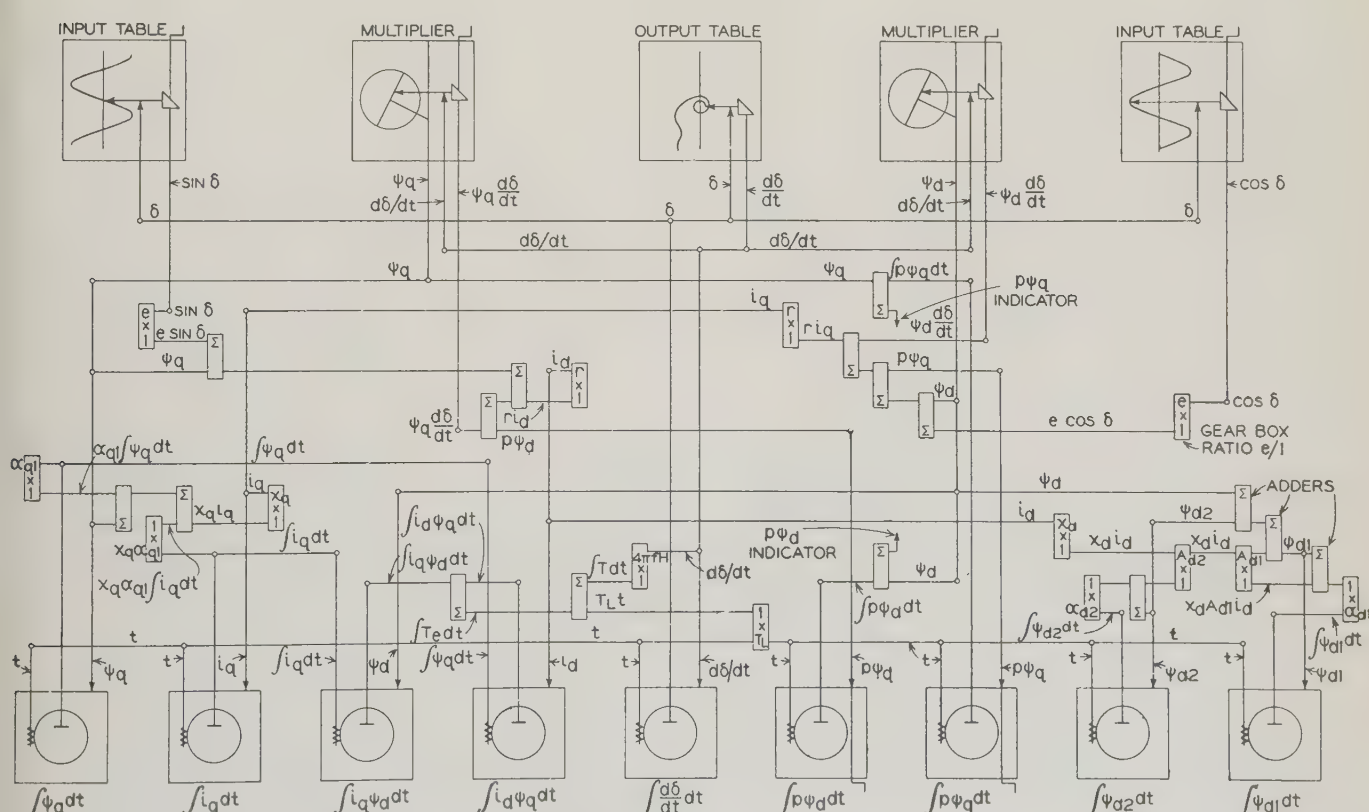


Fig. 2. Schematic diagram of differential analyzer connections for solution of synchronous motor equations

for the loads chosen. The steady state displacement angles corresponding to synchronous operation checked with the calculated values. Several synchronizing runs that were repeated in part or in entirety, showed gratifying correspondence. The most frequent check of solution accuracy consisted of an examination of the equality of equations 1, 2, and 9.

Results of Solutions

The constants of a machine having induction motor characteristics as shown in figure 1, are:

	With Discharge Resistor 8.5 Times Field Resistance	With Discharge Resistor Out
x_d	1.0	1.0
x_q	0.793	0.793
x_q''	0.341	0.341
A_{d1}	0.556	0.521
A_{d2}	0.125	0.160
α_{d1}	0.0087	0.000977
α_{d2}	0.160	0.1405
α_{q1}	0.0469	0.0469
B_{d1}		.681
B_{d2}		−3.43
E_{fd}		0.00312
H	0.898	0.898

The performance of this motor is illustrated in figures 3, 4, and 5.

The first step in determining the characteristics of a particular motor was to make several induction motor runs with selected load conditions. Each of these runs was carried to a point where the slip oscillations were repetitive. The settings of the integrator dials then were plotted for a complete slip cycle. The values from these curves were used in making initial settings for all subsequent synchronizing runs. This procedure assumes that the motor is permitted to attain its minimum average slip before field excitation is applied.

Figure 3 shows the performance of this machine as an induction motor when carrying various loads, with the discharge resistor in the field circuit. The values of slip are plotted against angle for purposes of comparison, although a plot against time as an independent variable is also possible. This latter would be, of course, the result shown on the usual oscillographic record.

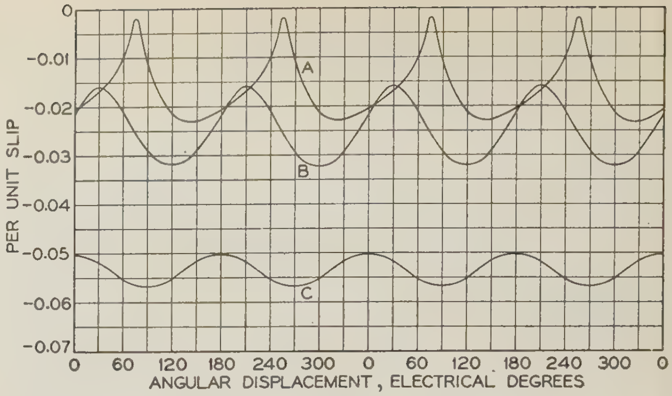


Fig. 3. Slip-angle relationship of induction motor cycle

Curve *A*—Load torque = 38.5 per cent
Curve *B*—Load torque = 50 per cent
Curve *C*—Load torque = 60 per cent

In accordance with the nomenclature under which the equations were derived, negative displacement angle denotes motor operation. Consequently, all curves in this paper in which angle is the abscissa progress from right to left in the negative slip region corresponding to induction motor operation.

Curve *A* of figure 3 is particularly significant, indicating as it does that the motor almost attains synchronous speed each 180 degrees. This is primarily attributable to the component of torque contributed by the direct axis field winding. The sharpness of the peak in the slip curve is deceptive from the point of view of time, and it should be borne in mind that the slip is plotted against angle and that the smaller the slip the greater the time interval for a given change in angular position.

Figure 4 is a family of curves illustrating the performance of the machine in synchronizing 50 per cent load from the ultimate induction motor speed. The induction motor slip curve is shown as a broken line and each of the synchronizing curves has its origin on this curve. The curves that indicate synchronization were carried only to the point where synchronous speed was reached. The form of the curve from this point to the steady state angular position is a spiral, a typical one being shown in figure 7. Some of the curves representing the performance where the machine did not synchronize have been carried sufficiently far to indicate that at the next minimum slip point the slip is greater than on the previous peak. This indicates that, for this load at least, the motor must synchronize on the first power swing or it never will synchronize, but at best will continue

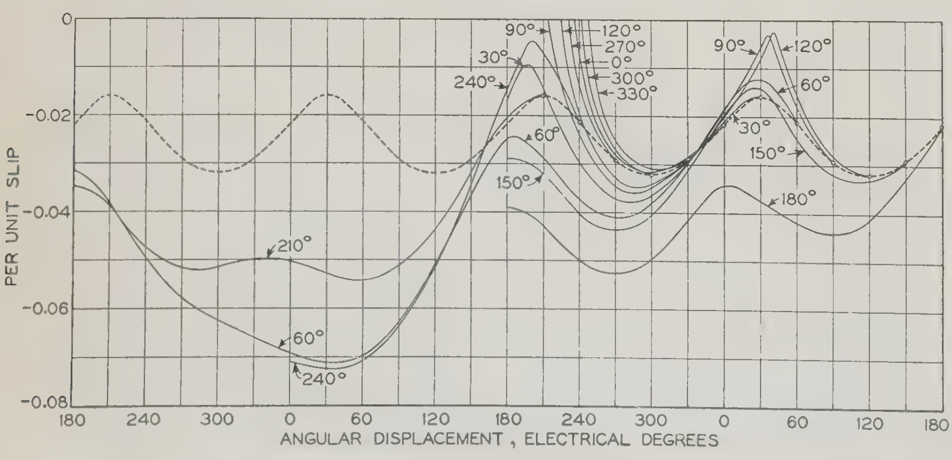


Fig. 4. Synchronizing performance with 50 per cent load

The dotted curve represents the induction motor cycle; other curves are identified by numerals representing the respective angles at which excitation was applied

to operate at some subsynchronous speed.

For 50 per cent load there are 2 angular zones in which excitation may be applied, resulting in synchronization. The most favorable zone is near the zero angle, but slightly in the motor region at an angle of approximately 330 degrees. This is the point at which the induced current in the field winding passes through zero, increasing in the positive direction; here the field flux linkages are a maximum. If at this point the discharge resistor be removed from the circuit and excitation applied, conditions will be most favorable for the motor pull into step. This is indicated by the fact that when synchronous speed is attained, the deviation from the steady state angle is less when excitation is applied here than for the application of excitation at any other point.

A significant factor in the synchronizing of salient pole synchronous motors is that a discharge resistance many times the normal field resistance may be employed in order to bring the machine to the maximum possible speed on its induction motor characteristic. This gives the motor field circuit a relatively short time constant. When, however, the discharge resistor is switched out, the field time constant is greatly increased, thus trapping the flux linking the field circuit at that time. The motor then operates in accordance with its transient rather than its steady state characteristics. The excitation, if applied at the best angle, may have but little effect on the operation of the motor until synchronous speed is reached, except to maintain or slightly increase the initial trapped linkages.

The curves (figure 4) showing performance where excitation was applied at 90 and 120 degrees indicate that the motor almost pulled into step 180 degrees ahead of the normal point, that is, it tended to pull-in under the influence of the trapped negative linkages; but as it did so the combined effect of armature magnetomotive force and applied excitation reduced the negative linkages to a point where the motor could not develop sufficient torque to reach synchronous speed. The time that elapsed while the motor was near synchronous speed was sufficient to enable the armature reaction and applied excitation to reverse the linkages in the field circuit so that the motor then was able to synchronize before the end of the next half slip cycle. The average slip also was favorable because of the small slip attained under the influence of the negative linkages.

Where excitation was applied somewhat later, that is, at 60 or 30 degrees instead of 90 degrees, the motor did not speed up as it had previously but passed through the zero angle in a much shorter time with practically zero linkages in the field. It then was unable to synchronize at the proper angle and, because of the loss of induction motor torque caused by switching out the discharge resistor, slowed down and thereafter was unable to synchronize.

The most unfavorable time for the application of excitation was at an angle of approximately 240 degrees from which point the motor was unable to synchronize within that particular cycle because of the exceedingly short time before reaching the 180 degree point. The field linkages, however, were in the positive direction so that the next part of the swing was in the generator region, which caused the machine to slow down materially. Besides the induction motor torque being lessened, there were additional losses in the armature circuit resistance.

For a given value of field excitation there are combinations of load and inertia (WR^2) that may be synchronized from any angle even though excitation be applied at a slip considerably greater than that at which it normally would be applied. Figure 5 illustrates the action of this motor on synchronizing $38^1/_2$ per cent load where the machine had been operating long enough for the field to have built up to its ultimate value. Each successive cycle shows the slip decreasing slightly until on the last cycle the motor finally synchronized. To indicate that this was the maximum load this motor could synchronize with field applied in this manner, the last cycle of this curve was repeated with a load of $42^1/_2$ per cent. The dotted line at the left side of the chart shows that the minimum slip point, after one cycle, was greater than the value at the beginning. This indicated that the motor never would be able to synchronize a load torque materially greater than $38^1/_2$ per cent if field were applied under the most unfavorable conditions. It also indicates that for loads greater than $38^1/_2$ per cent, if the motor does not synchronize in the first swing it will not syn-

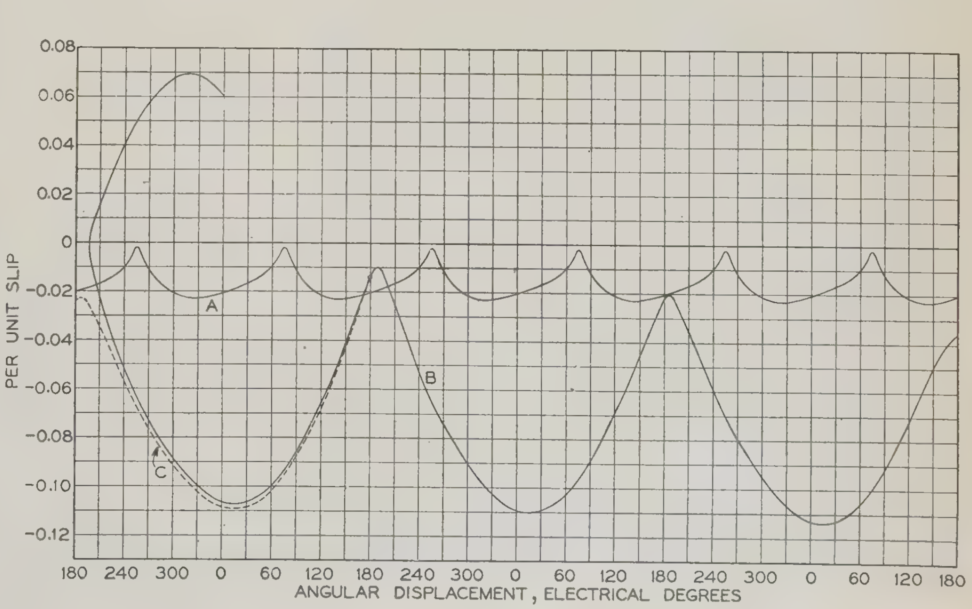


Fig. 5. Synchronizing performance with field excitation fully built up

Curve *A*—Induction motor cycle, 38.5 per cent load torque (Curve *A*, figure 3)

Curve *B*—Synchronizing cycle, 38.5 per cent load torque

Curve *C*—Synchronizing cycle, 42.5 per cent load torque

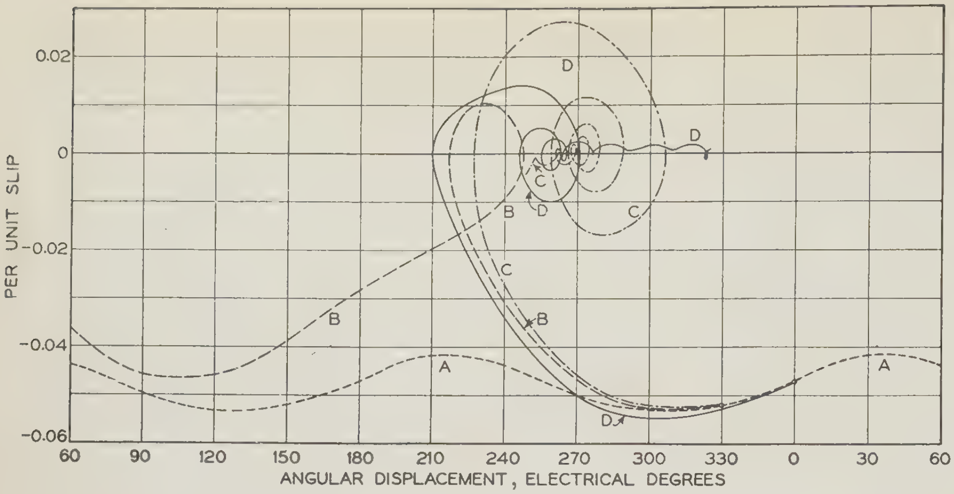


Fig. 6. Synchronizing performance of a machine with T_d' = 0.33 second; low excitation applied

Curve *A*—Induction motor cycle
Curve *B*—Zero excitation applied, field short-circuited at 300 degrees
Curve *C*—25 per cent excitation applied at 330 degrees
Curve *D*—40 per cent excitation applied at 0 degrees; steady state load angle 332 degrees

chronize ultimately. Other runs on this particular motor showed that from the most favorable switching angle, the machine could synchronize a maximum of 55 per cent load. A load of 50 per cent may be synchronized with field applied over a considerable range of angles as indicated in figure 4. This indicates a gain of approximately 40 per cent in the amount of load torque that may be synchronized by applying excitation under favorable conditions.

From the user's or operator's point of view, probably the greatest benefit to be obtained by properly applying the field excitation is the reduction of voltage dips. If the motor goes through several power swings in coming into synchronism, it may contribute materially to system disturbances in case its size is comparable with the feeder or system to which it is connected. In any event, the surge transmitted to the system in synchronizing will be a minimum when excitation is applied at the best angle and with the maximum possible average induction motor speed, for under these conditions the minimum amount of energy will be drawn from the system in the synchronizing swing. Following one or more power swings, even with light load, where excitation is applied at too low a speed, the slip at zero angle is greater than it would be if normal induction motor action were taking place (see figure 5). Thus the energy drawn from the system between zero angle and the point where synchronous speed is reached would be great even though the motor did synchronize, as the energy required is proportional to the square of the maximum slip.

Figure 6 is included as a matter of interest. Curve *B* shows the synchronizing action of a motor in which no excitation was applied, but at an angle of 330 degrees the discharge resistor was short-circuited, thus effectively trapping the flux linkages that were in the pole at that moment. The motor pulled into step and then, lacking excitation voltage to maintain these linkages, finally swung out of step. Curve *C* illustrates the action where the amount of excitation applied at 330 degrees was only slightly greater than that required to maintain synchronism under steady state conditions. The motor went through the synchronizing performance with several oscillations about synchronous speed, indicating perhaps that it finally would settle down to some steady operating angle. After a considerable lapse of time in a zone of unfavorable armature reaction, the flux linkages died down and the motor pulled out of step. This illustrates very clearly the fact that the initial performance of the motor is determined by the electrical transients rather than the steady state electrical phenomena.

Curve *D* illustrates the performance of the motor where excitation almost double that necessary to carry the load torque under steady state conditions was applied at an angle of zero degrees. Under these conditions, the pull-in was more difficult because of the less favorable angle. After pull-in, a spiral was generated; but as excitation built up, the motor finally broke from the spiral and moved toward its steady state angle.

A somewhat unique motor performance is indicated in figure 7. The family of curves is similar to that shown in figure 4, but represents the performance of a machine with a higher resistance amortisseur winding and a higher value of discharge resistance. The trapped flux linkage phenomena is illustrated strikingly by the curves beginning at 90 and 120 degrees. In both instances the motor reached synchronous speed under the influence of the trapped negative linkages, but then pulled out as the effect of the applied excitation was realized. The cycle beginning at 90 degrees resulted in ultimate synchronous operation while that from 120 degrees did not, the difference resulting from a smaller amount of trapped negative linkages and a longer elapsed time for the former.

Criteria

Criteria for pulling into step are presented in appendixes II and III for the performance of motors when the field excitation is applied at the most favorable and at the most unfavorable angles.

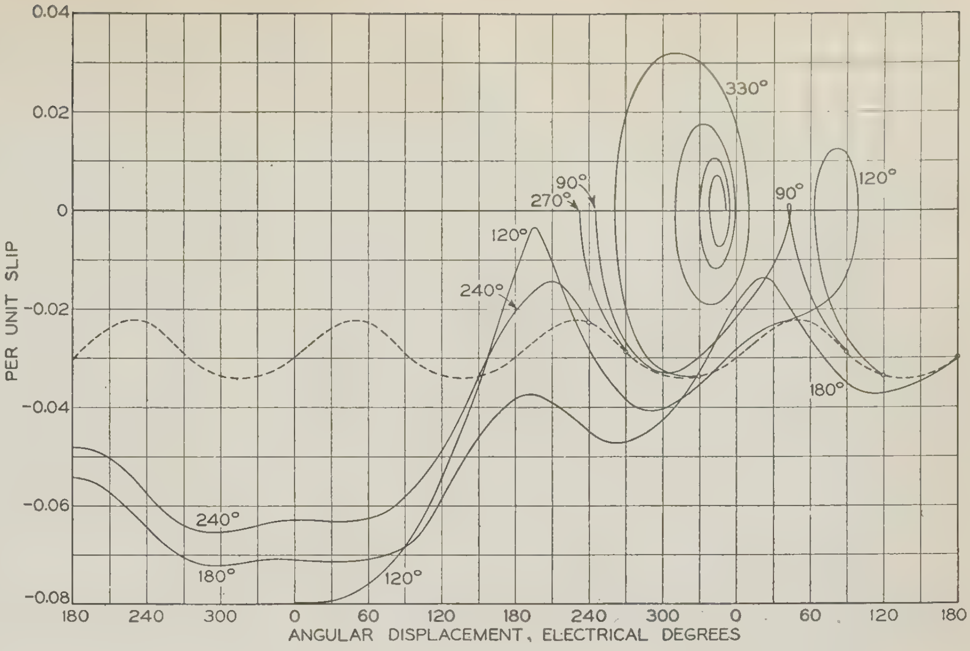
The criterion for the most favorable angle as developed in appendix II is

$$T_L < \left\{ \frac{2E_{d'(\max)}e}{\pi x_d'} + \frac{3}{8}e^2 s_0 \left[\frac{x_d' - x_d''}{x_d' x_d''} T_d'' + \frac{x_q - x_q''}{x_q x_q''} T_q'' \right] - 2fHs_0^2 - \left(\frac{E_{d'(\max)}}{x_d'} \right)^2 r \right\} \quad (30)$$

That is, in order to synchronize, the load torque T_L should be less than the sum of the other terms. The

Fig. 7. Synchronizing performance of machine with high resistance amortisseur winding

The dotted curve represents the induction motor cycle; other curves are identified by numerals representing the respective angles at which excitation was applied



first term inside the brackets results from the synchronous component of torque produced by the trapped flux linkages, the second from the amortisseur windings, the third from the inertia load, and the fourth from the primary circuit resistance losses.

Both $E_d'_{(max)}$ and s_0 can be calculated for practical purposes on the basis of constant slip. The remaining coefficients are constants for any given motor. This formula is adapted particularly to motors having long field time constants, as it assumes constant field flux linkages during the synchronizing period. However, for small machines with short field time constants the terms

$$\frac{2E_d'_{(max)}}{\pi x_d'} \text{ and } \left(\frac{E_d'_{(max)}}{x_d'}\right)^2 r$$

can be replaced by

$$\frac{2E_{de}}{\pi x_d} \text{ and } \left(\frac{E_d}{x_d}\right)^2 r$$

respectively, in order to show the effect of a very fast time constant, that is,

$$T_L < \left\{\frac{2E_{de}}{\pi x_d} + \frac{3}{8}e^2 s_0\left[\frac{x_d' - x_d''}{x_d' x_d''}T_d'' + \frac{x_q - x_q''}{x_q x_q''}T_q''\right] - 2fHs_0^2 - \left(\frac{E_d}{x_d}\right)^2 r\right\} \quad \text{(30a)}$$

If there be an appreciable difference between the load torque that can be pulled into step on the basis of constant field flux linkages (equation 30) as compared with that determined using equation 30*a*, a simple step-by-step calculation can be made to determine the approximate time angle relation for the motor during the synchronizing period and a corresponding correction made as follows:

$$T_L < \left\{k_1\frac{2E_d'_{(max)}e}{\pi x_d'} + \frac{3}{8}e^2 s_0\left[\frac{x_d' - x_d''}{x_d' x_d''}T_d'' + \frac{x_q - x_q''}{x_q x_q''}T_q''\right] - 2fHs_0^2 - \left(k_1\frac{E_d'_{(max)}}{x_d'}\right)^2 r\right\} \quad \text{(30b)}$$

where k_1 is a correction factor to take into account the increase in the field flux linkages during the synchronizing period.

Figure 8 is a diagram illustrating by means of areas the different components of equation 30 for the machine having the constants tabulated hereinbefore. The load component for the synchronizing period is represented by area A and the inertia component by area B. In order to synchronize, D must be greater than $B + C$. The criterion is slightly pessimistic, for in accordance with equation 30 D must be greater than $B + C + E$, since the components of torque used in deriving the criterion were integrated from 0 to -180 degrees. This discrepancy is not great, as area E is small.

The criteria as given by equations 30, 30*a*, and 30*b* provide a comparatively simple method of predetermining the load that can be pulled into step from the most favorable angle. These criteria checked the results obtained on the differential analyzer with good accuracy.

The criterion for the most unfavorable angle as developed in appendix III is

$$s_{(av)} < k_2\sqrt{\frac{E_{de}}{\pi f H x_d}} \quad \text{(38)}$$

That is, $s_{(av)}$ must be less than the right hand term of equation 38. This criterion is based upon the consideration that if the motor is capable of pulling into step from a subsynchronous speed, after the field has been fully built up, it will be able to pull into step if excitation be applied at the most unfavorable angle, even though the motor may slip several poles. In equation 38, $s_{(av)}$ is the average slip resulting from the torque developed by the machine when running out of synchronism with the field fully excited, and k_2 is the ratio between the average slip $s_{(av)}$ and the total slip pulsation s_p. From the differential analyzer results, $k_2 = 0.55$ to 0.60. This value of slip, $s_{(av)}$ is approximated by the average slip during the last slip cycle, for example, curve B, figure 5.

Equation 38 is almost identical with that given in reference 9, equation 5, if $k_2 = 0.50$, except that the average slip is determined by the net average torque available with the field fully excited (curve C, figure 1) and not by the induction motor characteristic with discharge resistor in the circuit (curve A, figure 1).

Nomenclature

All constants are in per unit values in terms of normal kilovolt-amperes and voltage, and correspond wherever possible with established nomenclature.[1,4,6] The following definitions are in terms of a rotating field machine:

x_d = synchronous reactance of direct axis armature circuit
x_d' = direct axis transient reactance
x_d'' = direct axis subtransient reactance
x_{a1d} = mutual reactance of armature with the additional direct axis rotor circuit
x_{afd} = mutual reactance of armature with the main field
$x_d(p)$ = impedance operator relating the direct axis armature flux linkages with the direct axis armature current
x_q = synchronous reactance of quadrature axis armature circuit
x_q'' = quadrature axis subtransient reactance
x_{a1q} = mutual reactance of armature with the quadrature axis rotor circuit
$x_q(p)$ = impedance operator relating the quadrature axis armature flux linkages with the quadrature axis armature current
X_{f1d} = mutual reactance of the main field with the additional direct axis rotor circuit
X_{11d} = self-inductive reactance of additional circuit in the direct axis
= x_{afd} + additional direct axis rotor circuit leakage reactance
X_{ffd} = self-inductive reactance of main field circuit
= x_{afd} + main field leakage reactance
X_{11q} = self-inductive reactance of rotor circuit in the quadrature axis
$G(p)$ = impedance operator relating the direct axis armature flux linkages with the field excitation voltage
r = armature circuit resistance
R_{1d} = resistance of additional direct axis rotor circuit
R_{fd} = field circuit resistance
R_{1q} = resistance of quadrature axis rotor circuit
e = system voltage
E_d = direct axis voltage corresponding to the field excitation
E_d' = voltage back of transient reactance
$= \frac{x_{afd}}{X_{ffd}} \psi_{fd}$
$E_d'_{(\max)}$ = voltage back of transient reactance corresponding to the maximum field flux linkages during the induction motor cycle
E_{fd} = field excitation voltage
ψ_d = direct axis armature winding flux linkages
ψ_{d1} = a component of direct axis armature winding flux linkages (see equation 12, appendix I)
ψ_{d2} = a component of direct axis armature winding flux linkages (see equation 13, appendix I)
ψ_{fd} = main field winding flux linkages
ψ_q = quadrature axis armature winding flux linkages
i_d = direct axis armature current
i_q = quadrature axis armature current
T_d'' = direct axis amortisseur (short circuit) time constant in electrical radians
T_q'' = quadrature axis amortisseur (short circuit) time constant in electrical radians
α_d = root of the denominator of $x_d(p)$
α_q = root of the denominator of $x_q(p)$
A_{d1} = equation 17, appendix I
A_{d2} = equation 18, appendix I
B_{d1} = equation 19, appendix I
B_{d2} = equation 20, appendix I
t = time in electrical radians; unit time is the time required for the rotor to pass one electrical radian at normal frequency
p = d/dt
H = inertia constant
$= \frac{0.231 \times WR^2 \times (RPM)^2}{10^6 \times \text{base kva}}$
s = slip
s_0 = slip at $\delta = 0$ when machine is running out of synchronism
$s_{(av)}$ = average slip
s_p = slip pulsation
δ = angular displacement in electrical radians
T_L = mechanical load torque
T_e = electrical torque
f = normal frequency in cycles per second
$\mathbf{1}$ = Heaviside's unit function used in this paper to indicate the application of voltage to the field circuit
k_1 = a correction factor to take into account the increase in the field flux linkages during the synchronizing period
k_2 = ratio between the average slip $s_{(av)}$ and the total slip pulsation s_p

Appendix I—Fundamental Relations

The following general relations are given by Park[4] for a synchronous machine:

$$e_d = p\psi_d - ri_d - \psi_q p\theta \tag{1}$$

$$e_q = p\psi_q - ri_q + \psi_d p\theta \tag{2}$$

$$\psi_d = G(p)E_{fd} - x_d(p)i_d \tag{3}$$

$$\psi_q = -x_q(p)i_q \tag{4}$$

$$T_e = i_q\psi_d - i_d\psi_q \tag{5}$$

where

$$e_d = e \sin \delta$$

$$e_q = e \cos \delta$$

$$p\theta = 1 + \frac{d\delta}{dt}$$

when the machine is connected directly to an infinite bus.

It is assumed that the amortisseur winding may be represented with reasonable accuracy by 2 closed circuits on the rotor, one in the direct axis, the other in the quadrature axis. On this basis the operators may be evaluated as follows:[6]

$$G(p) = \frac{p(X_{11d}x_{afd} - X_{f1d}x_{a1d}) + x_{afd}R_{1d}}{p^2(X_{11d}X_{ffd} - X^2_{f1d}) + p(X_{11d}R_{fd} + X_{ffd}R_{1d}) + R_{1d}R_{fd}} \tag{6}$$

$$x_d(p) = x_d - \frac{p^2(X_{11d}x^2_{afd} - 2X_{f1d}x_{a1d}x_{afd} + X_{ffd}x^2_{a1d}) + p(x^2_{afd}R_{1d} + x^2_{a1d}R_{fd})}{p^2(X_{11d}X_{ffd} - X^2_{f1d}) + p(X_{11d}R_{fd} + X_{ffd}E_{1d}) + R_{1d}R_{fd}} \tag{7}$$

$$x_q(p) = x_q - \frac{px^2_{a1q}}{pX_{11q} + R_{1q}} \tag{8}$$

Equations 3 and 4, which include the operational impedance operators, were modified in the following manner in order to bring them to a form suitable for solution by means of the differential analyzer:

Let

$$\psi_d = -x_d i_d + \psi_{d1} + \psi_{d2} \tag{9}$$

where

$$\psi_{d1} = \frac{x_d(A_{d1}pi_d + \alpha_{d1}B_{d1}E_{fd})}{p + \alpha_{d1}} \tag{10}$$

$$\psi_{d2} = \frac{x_d(A_{d2}pi_d + \alpha_{d2}B_{d2}E_{fd})}{p + \alpha_{d2}} \tag{11}$$

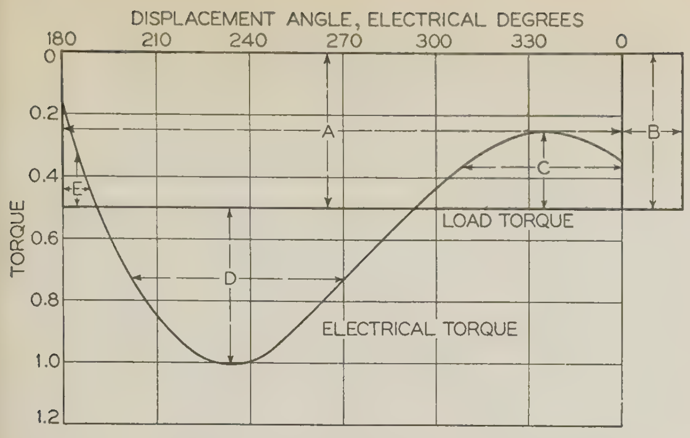


Fig. 8. Energy diagram where excitation is applied at the most favorable angle

A—Load area
B—Kinetic energy area
To synchronize, $D > B + C$
E—Refer to appendix II

From equation 10,

$$\psi_{d1} = x_d A_{d1} i_d + \frac{x_d B_{d1} \alpha_{d1} E_{fd}}{p} - \frac{x_d \alpha_{d1}(A_{d1} p i_d + \alpha_{d1} B_{d1} E_{fd})}{p(p + \alpha_{d1})}$$

Hence,

$$\psi_{d1} = x_d A_{d1} i_d - \alpha_{d1} \int (\psi_{d1} - x_d B_{d1} E_{fd}) dt \tag{12}$$

In a similar manner it may be shown that

$$\psi_{d2} = x_d A_{d2} i_d - \alpha_{d2} \int (\psi_{d2} - x_d B_{d2} E_{fd}) dt \tag{13}$$

From equations 3 and 9,

$$\psi_{d1} + \psi_{d2} = [x_d - x_d(p)] i_d + G(p) E_{fd} \tag{14}$$

The coefficients of equations 12 and 13 may be obtained by substituting equations 6, 7, 10, and 11 in equation 14 and dividing both numerator and denominator of the right hand member by $(X_{11d}X_{ffd} - X^2{}_{f1d})$. The denominator of the resulting expression is

$$p^2 + p\frac{X_{11d}R_{fd} + X_{ffd}R_{1d}}{X_{11d}X_{ffd} - X^2{}_{f1d}} + \frac{R_{1d}R_{fd}}{X_{11d}X_{ffd} - X^2{}_{f1d}}$$

and may be factored to obtain

$$\alpha_{d1} = \frac{X_{11d}R_{fd} + X_{ffd}R_{1d} - \sqrt{X^2{}_{11d}R^2{}_{fd} + X^2{}_{ffd}R^2{}_{1d} - 2X_{11d}R_{fd}X_{ffd}R_{1d} + 4X^2{}_{f1d}R_{1d}R_{fd}}}{2(X_{11d}X_{ffd} - X^2{}_{f1d})} \tag{15}$$

$$\alpha_{d2} = \frac{X_{11d}R_{fd} + X_{ffd}R_{1d} + \sqrt{X^2{}_{11d}R^2{}_{fd} + X^2{}_{ffd}R^2{}_{1d} - 2X_{11d}R_{fd}X_{ffd}R_{1d} + 4X^2{}_{f1d}R_{1d}R_{fd}}}{2(X_{11d}X_{ffd} - X^2{}_{f1d})} \tag{16}$$

where α_{d1} and α_{d2} represent the open circuit decrement factors of the field and amortisseur windings, respectively.

The constant terms and the coefficients of p and p^2 in the identity resulting from equation 14 may be equated and solved simultaneously with the following results:

$$A_{d1} = \frac{\alpha_{d1}(x_d - x_d'')}{x_d(\alpha_{d1} - \alpha_{d2})} - \frac{x^2{}_{afd}R_{1d} + x^2{}_{a1d}R_{fd}}{x_d(\alpha_{d1} - \alpha_{d2})(X_{11d}X_{ffd} - X^2{}_{f1d})} \tag{17}$$

$$A_{d2} = \frac{x^2{}_{afd}R_{1d} + x^2{}_{a1d}R_{fd}}{x_d(\alpha_{d1} - \alpha_{d2})(X_{11d}X_{ffd} - X^2{}_{f1d})} - \frac{\alpha_{d2}(x_d - x_d'')}{x_d(\alpha_{d1} - \alpha_{d2})} \tag{18}$$

$$B_{d1} = \frac{\alpha_{d1}(X_{11d}x_{afd} - X_{f1d}x_{a1d}) - x_{afd}R_{1d}}{x_d\alpha_{d1}(\alpha_{d1} - \alpha_{d2})(X_{11d}X_{ffd} - X^2{}_{f1d})} \tag{19}$$

$$B_{d2} = \frac{x_{fd}R_{1d} - \alpha_{d2}(X_{11d}x_{afd} - X_{f1d}x_{a1d})}{x_d\alpha_{d2}(\alpha_{d1} - \alpha_{d2})(X_{11d}X_{ffd} - X^2{}_{f1d})} \tag{20}$$

From equations 4 and 8,

$$\psi_q = -x_q i_q + \frac{p x^2{}_{a1q}}{pX_{11q} + R_{1q}} i_q$$

which may be expanded to

$$\psi_q = -i_q\left[x_q - \frac{x^2{}_{a1q}}{X_{11q}}\right] - \frac{R_{1q}}{pX_{11q}}\left[\frac{p x^2{}_{a1q} i_q}{pX_{11q} + R_{1q}}\right] \tag{21}$$

Substituting,[6]

$$x_q'' = x_q - \frac{x^2{}_{a1q}}{X_{11q}} \quad \text{and} \quad \alpha_{q1} = \frac{R_{1q}}{X_{11q}}$$

there results

$$\psi_q = -x_q'' i_q - \alpha_{q1}\int \psi_q dt - \alpha_{q1} x_q \int i_q dt \tag{22}$$

The summation of instantaneous torques acting upon the mechanical system must be zero. Consequently, accelerating torque = − electrical torque − load torque. Accordingly,

$$4\pi f H \frac{d^2\delta}{dt^2} = i_d\psi_q - i_q\psi_d - T_L \tag{23}$$

where

$$H = \frac{0.231\, WR^2(\text{rpm})^2}{10^6 \text{ base kva}} \tag{24}$$

Equation 23 is given in reference 4, equation 57*A*.

The fundamental equations of a synchronous machine arranged for simultaneous solution on the differential analyzer are therefore equations 1, 2, 9, 12 13, 22, and 23.

Appendix II—Criterion for Synchronizing at the Most Favorable Switching Angle

The criterion for synchronizing at the most favorable switching angle as derived in this appendix, is based upon the following assumptions and considerations:

1. The most favorable time to apply field excitation is at the instant of maximum main field winding flux linkages when the polarity of these flux linkages corresponds to that resulting from the applied field excitation.
2. The main field winding flux linkages existing at the instant the exciter switch is closed are constant during the synchronizing period, that is, the time from the instant the exciter switch is closed to the instant the slip is zero. This in effect assumes that the applied field excitation is just sufficient to prevent the armature reaction magnetomotive force from decreasing the field flux linkages during the synchronizing period. This is particularly justifiable in the case of large motors, where the synchronizing period from the best angle is relatively short compared with the field time constant when the discharge resistor is not in the field circuit.
3. The synchronizing period is assumed to begin at $\delta = 0$, with field flux linkages corresponding to the maximum obtained during the induction motor cycle. This assumption is justifiable, although the maximum field flux linkages are not obtained at $\delta = 0$ but at about 330 or −30 degrees, since the electrical torque between 0 and −30 degrees is not appreciably different whether the machine is running as an induction motor with the discharge resistance in or with constant maximum induction-motor-cycle flux linkages in the main field circuit.
4. The synchronizing period is assumed to end at $\delta = \pi$. This leads to a slightly pessimistic result. The error is small as the electrical torque is decreasing rapidly as a function of δ, at $\delta = 180$ degrees. This error is shown in figure 8 by the small area *E*.
5. The torque developed by the amortisseur windings during the synchronizing period is assumed equal to the average of that obtained

on the basis of the slip remaining constant from $\delta = 0$ to $\delta = \pi$ and the slip decreasing linearly from $s = s_0$ at $\delta = 0$ to $s = 0$ at $\delta = \pi$. This assumption was considered as a reasonable approximation from an analysis of the differential analyzer results. See figures 4, 6, and 7 for switching at $\delta = 330$ degrees.

6. Normal values of armature circuit resistance have been found to have a negligible effect on the induction motor components of electrical torque, while the effect of the synchronous component is taken into account approximately by adding to the synchronous component of torque determined by neglecting resistance, the term

$$\left(\frac{E_d'(\max)}{x_d'}\right)^2 r.$$

Integrating equation 23 (appendix I),

$$2\pi fH\left(\frac{d\delta}{dt}\right)^2 = \int_0^{-\pi}(-T_L - T_e)d\delta + 2\pi fHs_0^2 \qquad (25)$$

For synchronizing, $d\delta/dt$ must equal zero. Letting $d\delta/dt = 0$ in equation 25, and since T_L is a constant

$$\pi T_L = \int_0^{-\pi} T_e d\delta - 2\pi fHs_0^2 \qquad (26)$$

where, on the basis of assumptions 2 and 6, equation 14 of reference 3, and equation 61 of reference 5,

$$T_e = \frac{E_d'(\max)e}{x_d'}\sin\delta + \frac{e^2(x_d' - x_q)}{2x_d'x_q}\sin 2\delta + \frac{e^2(x_d' - x_d'')}{x_d'x_d''}sT_d''\sin^2\delta + \frac{e^2(x_q - x_q'')}{x_qx_q''}sT_q''\cos^2\delta + \left(\frac{E_d'(\max)}{x_d'}\right)^2 r \qquad (27)$$

In accordance with assumption 5,

$$s = \frac{1}{2}\left[s_0 + \left(1 - \frac{\delta}{\pi}\right)s_0\right] \qquad (28)$$

Substituting equation 28 in equation 27 and integrating with respect to δ between 0 and $-\pi$,

$$\int_0^{-\pi} T_e d\delta = \frac{2E_d'(\max)e}{x_d'} + \frac{3}{8}e^2\pi s_0\left[\frac{x_d' - x_d''}{x_d'\,x_d''}T_d'' + \frac{x_q - x_q''}{x_qx_q''}T_q''\right] - \left(\frac{E_d'(\max)}{x_d'}\right)^2 r\pi \qquad (29)$$

Substituting equation 29 in equation 26, the criterion for synchronizing at the most favorable angle is

$$T_L < \left[\frac{2E_d'(\max)e}{\pi x_d'} + \frac{3}{8}e^2s_0\left(\frac{x_d' - x_d''}{x_d'x_d''}T_d'' + \frac{x_q - x_q''}{x_qx_q''}T_q''\right) - 2fHs_0^2 - \left(\frac{E_d'(\max)}{x_d'}\right)^2 r \right. \qquad (30)$$

The first term inside the brackets of equation 30 results from the synchronous component of transient torque, the second term from the component of torque contributed by the amortisseur winding, the third term from the kinetic energy component of torque, and the fourth term from the armature circuit resistance losses. In using this criterion it is necessary to make a preliminary set of calculations in order to determine the average slip, s_0, for a given load, and the quantity $E_d'(\max)$ when operating at this slip as an induction motor. These preliminary calculations can be made on the basis of constant slip, with sufficient accuracy for practical purposes.

Appendix III—Criterion for Synchronizing With Excitation Applied at the Most Unfavorable Angle

The criterion for synchronizing with excitation applied at the most unfavorable angle is based on the following assumptions and considerations.

1. It is assumed that the motor will pull into step with excitation applied at the most unfavorable angle if it is capable of pulling into step after slipping several poles with the field excitation fully built up.

2. It is assumed that the fundamental angular component of electrical torque when running out of synchronism is equal to $[(E_de)/x_d]\sin\delta$, where E_d is a voltage corresponding to the field excitation. This is essentially correct for this case since the average field current induced by the motion is approximately zero over a complete slip cycle.

3. Since the pulsating component of synchronous torque produced by the field excitation when the motor is running out of synchronism is large compared with the other components of pulsating torque, it is assumed that minimum slip is 180 degrees from maximum slip (see figure 5).

4. The electrical torque is assumed to be made up of a constant term, a fundamental angular component of torque (synchronous torque), and even angular harmonics of electrical torque (induction and reluctance torques).

Integrating equation 23 (appendix I) from δ_1 to δ_2 in order to find the magnitude of the slip pulsation, $\left[s_p = \frac{d\delta_2}{dt} - \frac{d\delta_1}{dt}\right]$,

$$2\pi fH\left(\frac{d\delta_2}{dt}\right)^2 = -\int_{\delta_1}^{\delta_2}(T_L + T_e)d\delta + 2\pi fH\left(\frac{d\delta_1}{dt}\right)^2 \qquad (31)$$

Since at synchronous speed $(d\delta_2)/(dt) = 0$ the magnitude of the slip pulsation, s_p, for the slip cycle before synchronization is equal to $-(d\delta_1)/(dt)$. Accordingly, equation 31 becomes

$$2\pi fHs_p^2 = \int_{\delta_1}^{\delta_2}(T_L + T_e)d\delta \qquad (32)$$

In accordance with assumption 3, $\delta_2 = \delta_1 - \pi$, and equation 32 can be expressed as follows

$$2\pi fHs_p^2 = \int_{\delta_1}^{\delta_1-\pi}\frac{E_de}{x_d}\sin\delta d\delta + \int_{\delta_1}^{\delta_1-\pi}(T_1 + T_L)\,d\delta \qquad (33)$$

where, in accordance with assumption 4,

$T_1 = T_e - \frac{E_de}{x_d}\sin\delta$ = the constant component plus the even angular harmonic components of the electrical torque.

Since for a complete cycle,

$$\int_{\delta_1}^{\delta_1-2\pi}(T_L + T_e)d\delta = 0 \quad \text{and} \quad \int_{\delta_1}^{\delta_1-2\pi}\frac{E_de}{x_d}\sin\delta d\delta = 0$$

then

$$\int_{\delta_1}^{\delta_1-\pi}(T_1 + T_L)\,d\delta = 0 \qquad (34)$$

Substituting equation 34 in equation 33 and integrating,

$$2\pi fH\,s_p^2 = \frac{2E_de}{x_d}\cos\delta_1 \qquad (35)$$

or

$$s_p = \sqrt{\frac{E_de}{\pi fH\,x_d}\cos\delta_1} \qquad (36)$$

For the magnitude of pulsation to be a maximum, $\delta_1 = 0$ and equation 36 becomes

$$s_p = \sqrt{\frac{E_de}{\pi fH\,x_d}} \qquad (37)$$

Assuming the average slip to be k_2s_p, the criterion for synchronizing from the most unfavorable angle is

$$s_{(\mathrm{av})} < k_2\sqrt{\frac{E_de}{\pi fH\,x_d}} \qquad (38)$$

where from the differential analyzer solutions $k_2 = 0.55$ to 0.60.

Since the average slip can be determined approximately from calculations based upon constant slip, equation 38 provides a means for determining whether or not a motor will pull in from the most unfavorable angle.

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Discharge Currents in Distribution Arresters

With a view to augmenting the meager data available on the discharge currents through lightning arresters on electric power distribution circuits, the investigation reported in this paper, which covered 4 power systems of various voltages and in different sections of the country, was undertaken. Over the range of circuit voltages involved in this investigation (4 to 24 kv) voltage rating seemed to have no definite influence on the discharges. More negative than positive discharges were recorded, the ratio increasing as the discharge current increased. The maximum current recorded was 17,000 amperes.

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DURING the summer of 1934, the General Electric Company undertook a co-operative investigation with the Edison Electric Illuminating Company of Boston, the Commonwealth Edison Company of Chicago, the Detroit Edison Company, and the Georgia Power Company, having for its purpose the acquiring of data relative to discharge currents through distribution lightning arresters as the result of lightning. Much valuable work had been done on high voltage transmission lines during the preceding 10 years, leading to a better understanding of what hazards lightning may impose upon insulation and apparatus, both at the point of inception and as the result of wave travel along conductors. With the distribution circuit, however, conditions are frequently less definite, particularly with regard to insulation levels, effects of shielding, and effectiveness of grounding. Considerable data[1] have been published concerning the performance of distribution arresters, particularly as related to the failure of apparatus, but there have been almost no data available with reference to discharge currents through lightning arresters.

In 1934 were published the results of a 4 year study of lightning potentials obtained through the use of the surge voltage recorder[2] on the distribution lines in Chicago, Ill. At 8 locations the lightning discharge current through a special arrester was determined by measuring the potential across "thyrite" disks. Of 32 records obtained, 31 indicated currents of 300 amperes or less, while the remaining record indicated a current of the order of 1,500 amperes. These results were of too limited a character to permit drawing definite conclusions.

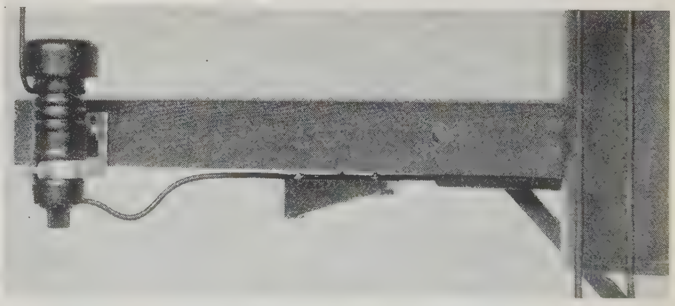

Fig. 1. Typical installation of magnetic links on ground lead of lightning arrester to measure lightning discharge current

A paper recommended for publication by the A.I.E.E. committee on protective devices, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted Oct. 17, 1935; released for publication Oct. 29, 1935.

1. For all numbered references see list at end of paper.

Later, currents of the order of 34,000 amperes through the common ground lead of 3 lightning arresters connected to a 24 kv circuit in a "non-shielded" area were reported.[3] In obtaining these results, the size of the hole punctured through paper inserted between 2 electrodes was used to indicate the magnitude of the current, calibration having been obtained through the use of the impulse generator and the cathode ray oscillograph.

The wide difference between the results obtained in these 2 investigations indicated the necessity of obtaining in the present investigation a considerable amount of data over a wide range of circuit voltage ratings and locations. Summarized briefly, the results obtained during the first year of the present investigation are as follows:

1. Circuit voltage rating, which sometimes may imply different line insulation, seems to have no definite influence on the occurrence of a discharge of given magnitude through a lightning arrester. The circuit ratings involved range from 4 kv to 11.95 kv for most of the installations.

2. Lumping all the data together without reference to location, the preponderance of negative records becomes greater at the larger currents. There were about 9 times as many negative as positive records at 5,000 amperes, and 2 times as many at 500 amperes. Apparently, the higher values are attributable to direct strokes, while at low currents an increasing proportion is attributable to induced effects.

3. The highest negative current measured was 17,000 amperes, and the highest positive current 14,000 amperes.

4. On the average, current of a given magnitude will be discharged through a rural arrester 3 1/4 times as often as through an urban arrester.

5. A lightning arrester installed in a rural area may be expected to discharge a current of 5,000 amperes or more once in 26 years, while the same arrester installed in an urban area would discharge such a current on the average of once in 76 years. The data indicate for 15,000 amperes or more an "expectancy" of 210 years for the rural arrester and 600 years for the urban arrester.

6. In applying these results to predict the number of discharges on any line, considerable variation from the foregoing results may be expected because of variations in the number and severity of storms, the degree of exposure of lines, and density of arresters on the lines.

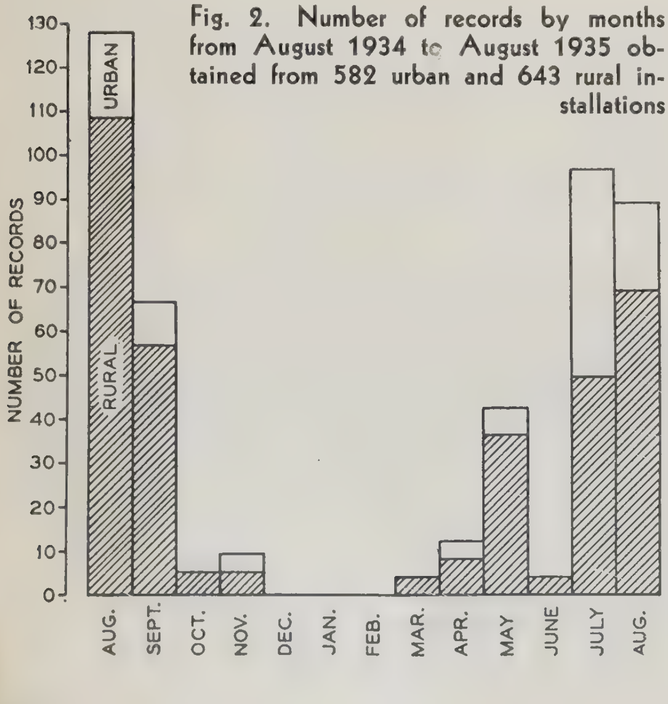

Fig. 2. Number of records by months from August 1934 to August 1935 obtained from 582 urban and 643 rural installations

Surge Crest Ammeter Used

Development of the magnetic link and surge crest ammeter[4] provided a simple and relatively inexpensive means of determining crest current. As used 2 magnetic links are mounted on a triangular wooden bracket as shown in figure 1, the bracket being placed over the arrester ground wire. The 2 links were spaced approximately 3/4 inch and 2 1/8 inches from the arrester ground wire for most installations.

Two magnetic links with different spacings were used so that their current ranges would overlap, thus making possible the measurement of a large range of currents. After these installations were made, experience obtained from investigations in the laboratory and on high voltage lines with similar equipment indicated that lightning discharges are not always unidirectional. It was found also that readings obtained on the links, as already installed, would give information regarding any reversals or oscillations of the discharge current as well as the crest amplitude.

Table I—Distribution of Surge Crest Ammeter Installations

Operating Company	Line Kv	Transformer Connection	Rural or Urban	Surge Crest Ammeter Installations: Number	Surge Crest Ammeter Installations: Per Cent on Interconnected Arresters**
Commonwealth Edison Co.	4	Grounded star	Urban	252	72
	4	Grounded star	Rural	69	41
	12	Grounded star	Rural	8	0
	20	..	Urban	2	
Detroit Edison Co.	4.8	Delta	Urban	30	0
	4.8	Delta	Rural	300	100
	24	Grounded..*	Rural	12	
Edison Elec. Illum. Co. of Boston	4	Ungrounded star	Urban	298	100
Georgia Power Co.	2.3	Delta	Rural	3	0
	6.9	Delta	Rural	74	100
	11.5	Delta	Rural	96	84
	11.95	Grounded star	Rural	81	100

Average length of service, corrected for difference in lightning severity for different months, 1.1 years for urban installations and 1.2 years for rural installations.

* All surge crest ammeter installations on 2,300-volt single-phase circuits.

** Lightning arrester ground and secondary neutral interconnected.

The current measurements obtained in this investigation are based upon laboratory calibration of the magnetic links, using an impulse generator and cathode ray oscillograph.[4] The impulse generator circuit constants were varied to give different degrees of damping, so that calibrations could be obtained for currents with different degrees of reversal.

The range of currents that can be read accurately with the surge crest ammeter, for the link spacings used, is from about 500 up to 5,000 or 7,500 amperes, depending upon the amplitude of reversal. Beyond these limits, knees in both ends of the magnetization curves make interpolation difficult on a scale of suitable length for a field instrument. Also, unless links are selected carefully, the differences between the characteristics of individual links are likely to introduce appreciable errors in readings above the range of the surge crest ammeter.

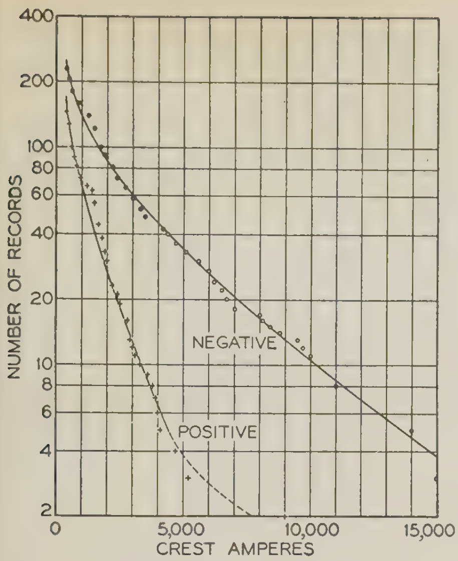

Fig. 3. Relative numbers of positive and negative discharges

Curves show number of discharges whose magnitude was at least as great as shown by the corresponding crest amperes. Based upon a total of 156 positive and 255 negative records from 1,225 installations

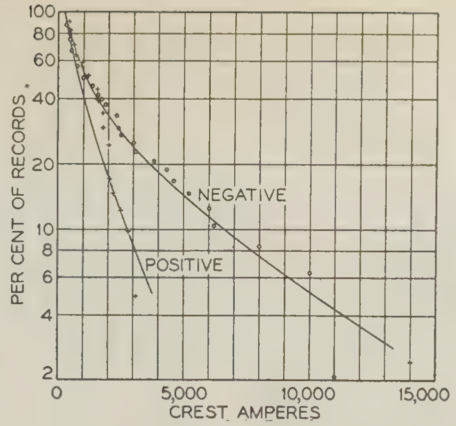

Fig. 4. Summary of 41 positive and 48 negative records obtained from 582 urban installations

Curves in figures 4 and 5 show per cent of discharges whose magnitude was at least as great as shown by the corresponding crest amperes

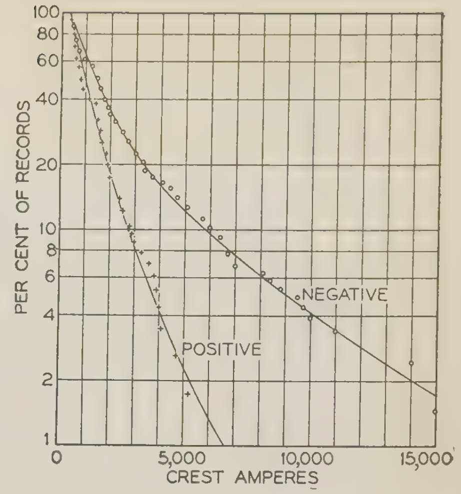

Fig. 5. Summary of 115 positive and 207 negative records obtained from 643 rural installations

In this investigation, readings outside the range mentioned could be made with a fair degree of accuracy, because all links were measured with a ballistic galvanometer, which has a scale length many times that of the surge crest ammeter. Also, links that were found to be strongly magnetized were calibrated individually to eliminate errors from variation in magnetization characteristics.

These measures permitted currents up to a maximum of 17,000 amperes to be measured fairly accurately, and also permitted currents less than 500 amperes, down to about 300 amperes, to be detected and read approximately. It is believed that the accuracy of measurement, except for the smaller currents, is within 10 per cent for single unidirectional waves or for damped oscillations of the type used in the laboratory calibration tests.

It is interesting to note that the smallest currents measured, when considered on a traveling wave basis, would correspond roughly to the lowest surge potentials that would be dangerous to typical distribution circuit insulation. Hence, practically all the current records obtained in the investigation represent surge magnitudes that would have been dangerous to unprotected transformers on the lower voltage circuits.

The procedure with each of the co-operating companies was much the same, in that inspection was made after each storm in so far as conditions would permit. An inspector examined each link using a special magnetic indicator built for the purpose. If magnetism was indicated, the link was enclosed in a special magnetic shield and sent to the laboratory where its magnetization was determined by the use of a ballistic galvanometer. Individual magnetization curves were taken for many links on which records had been obtained outside the normal calibration range. After test, the links were demagnetized and either held as spares or reinstalled.

A total of 1,225 installations have been in service for slightly more than a year, distributed as shown in table I.

Results

It is of interest to note the number of records obtained from the 4 systems for each month of the year. In figure 2, these data are shown divided into rural and urban records. The plot shows clearly the greater number of rural records compared with those from urban areas. Lightning during the months of May and September appears to be about half as severe as it is during July or August.

Polarity of Current. A total of 156 positive and 255 negative records (figure 3) was obtained from all of the 1,225 installations. Of a total of 411 records, 3 or 0.73 per cent were of 15,000 amperes or more, the highest being 17,000 amperes; these were all of negative polarity. The 2 highest positive values recorded were 9,000 and 14,000 amperes, respectively. At 5,000 amperes negative discharges were recorded about 9 times as frequently as were positive discharges. As the current becomes less this ratio decreases, being about 2 at 500 amperes.

It has been well established through the results of studies on high voltage transmission systems that direct strokes to lines are predominantly negative. Induced effects resulting from nearby strokes therefore will be predominantly positive, and of course will be of smaller magnitude. This probably explains the preponderance of negative records at the higher currents obtained in this investigation, and the increasing proportion of positive records at low currents.

Number of Records. With 411 records obtained on the 1,225 installations, approximately one record could be expected per arrester installation once every 3 years on the average. The data, as given in figure 3, show a total of 150 records of 1,500 amperes or more, which means, assuming the season recorded to be average, that an arrester could be expected to

discharge a current of at least 1,500 amperes once every 9 years. On the basis of 5,000 amperes or more, the total number of records is 38, indicating an expectancy of one such discharge every 35 years. Using the same reasoning, 28 arresters per 1,000 installed would be expected to carry a discharge current of at least 5,000 amperes in an average year.

Current Reversals. The majority of the discharges measured were found to contain reversals or oscillations. These reversals were quite consistently smaller for the high current discharges, being of the order of 5 per cent of the crest current for 10,000 ampere discharges, and 40 per cent for 1,000 ampere discharges.

Sufficient data have not been obtained to explain fully the cause or nature of these oscillations or reversals. However, their existence is indicated also by magnetic link records obtained on high voltage lines, and by recent oscillographic studies.[5]

Urban Results Compared With Rural Results. In built-up sections, it is to be expected that the duty on lightning arresters would be less severe because of the shielding effect of nearby buildings and other conducting structures, and also because of the reduced insulation resulting from the presence of grounded conductors on the same pole. In cities also, the density of arresters is likely to be higher, resulting in less current through a given arrester.

In figures 4 and 5, the data presented in figure 3 are segregated according to their sources in urban and rural locations. It is recognized that the division between urban and rural may be on a somewhat different basis in each of the systems studied, yet the great majority of the data so classified do represent comparable conditions. It should be noted that the curves are plotted in terms of per cent of total records rather than number of records as in figures 2 and 3. This allows a direct comparison between the rural and urban data. Plotted on this basis, very little definite difference can be detected between the current to be expected at urban locations and that at rural locations.

From 582 urban installations 41 positive and 48 negative records were obtained, while from 643 rural installations 115 positive and 207 negative records were obtained. In the urban areas there were 17 per cent more negative than positive records, while 79 per cent more negative than positive records were obtained from the rural areas. Of greater significance, however, is the comparison between the number of records obtained. When compared on the basis of an equal number of installations, $3^1/_4$ times as many records were obtained from the rural areas as from the urban areas. Since the shapes of the curves in figures 4 and 5 are similar, about the same ratio will apply to all current values. Additional data yet to be obtained in the continued investigation may show that adjustment of the curve shape is necessary since sufficient data on high positive currents are lacking as yet.

It is believed that the data obtained from this investigation will be of greatest use if presented in the form of expectancy curves, showing the number of years that may be expected to elapse before a current of a certain magnitude or greater passes through a given arrester. These curves will be modified of course as additional data become available, but the results thus far should represent a fair approximation. In figure 6 such expectancy curves are shown for all rural and urban installations, while in the following 3 figures the data are broken down still further with reference to system voltage rating.

Figure 6 indicates that a current of 1,500 amperes or more may be expected through a rural arrester once every 6 years, and once every 20 years through an urban arrester. At 5,000 amperes, the expectancy is respectively 26 and 76 years. Further study of figure 6 shows that a current of 15,000 amperes may be expected once every 210 years through the rural arrester, and once every 600 years through the urban arrester. Expressed in percentages, 0.17 per cent of the urban and 0.48 per cent of the rural arresters would be expected to discharge 15,000 amperes once during each year for which the lightning severity is equal to that covered by this investigation.

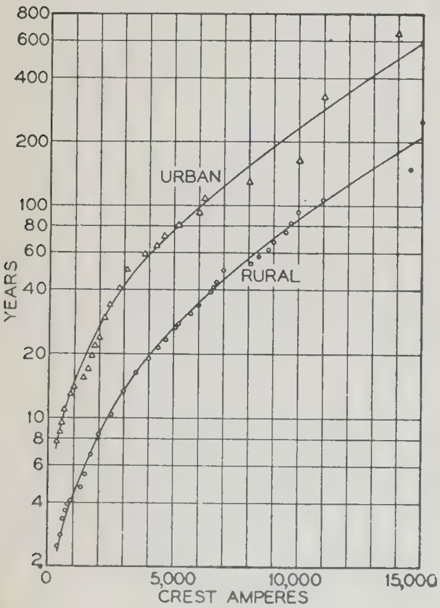

Fig. 6. Expectancy of discharge for urban and rural arresters

Curves show number of years at a given arrester location that may be expected to elapse before a current of at least the magnitude shown by the abscissa will pass through the arrester

Since the time duration of currents could not be measured by the magnetic links, it should be recognized that the current amplitudes alone are not a direct measure of the severity of duty on the arresters. A relatively low current of long duration may represent more severe duty than a very high current of short duration. However, it is significant that distribution arresters are available which appear to have discharge capabilities entirely commensurate with discharge duties on distribution circuits. More than 60 per cent of the field measurements involved a type of arrester with which no recorded discharge resulted in any failure of either the arrester or the protected transformer. This type was subjected to 75 per cent of the recorded discharges of 10,000 amperes or more, including the highest current of 17,000 amperes.

Effect of Interconnection of Arrester Ground and Secondary Neutral. An attempt was made to determine from the data what improvement in the protection of apparatus had been obtained at the locations where arrester grounds were interconnected with secondary neutrals. However, there were so

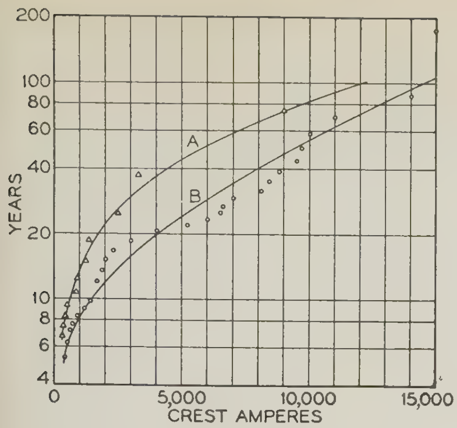

Fig. 7. Comparison of (A) 11 records obtained on 69 installations on 4-kv star-connected rural lines of the Commonwealth Edison Company, and (B) 71 records obtained from 300 installations on 4.8-kv delta-connected rural lines of the Detroit Edison Company

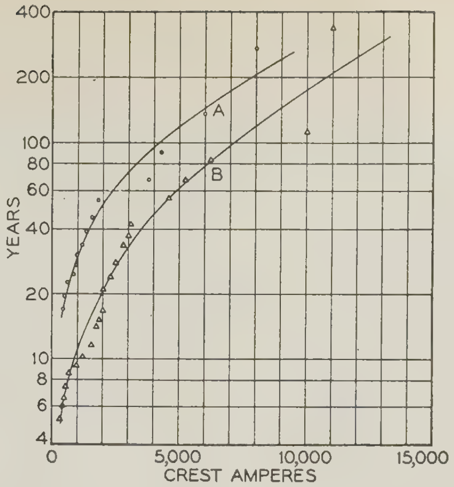

Fig. 8. Comparison of (A) 18 records obtained from 252 installations on 4-kv star-connected urban lines of the Commonwealth Edison Company, and (B) 67 records obtained from 298 installations on 4-kv star-con ected urban lines of the Edison Electric Illuminating Company of Boston

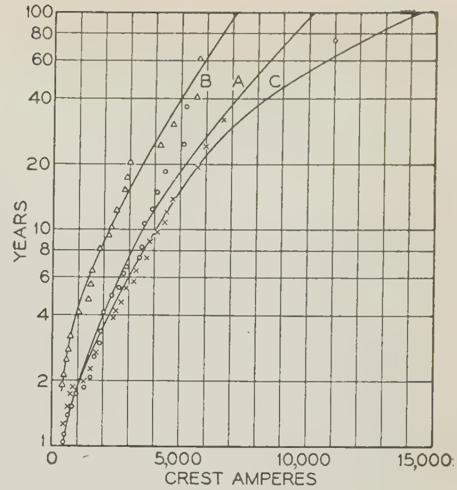

Fig. 9. Comparison of (A) 75 records obtained from 74 installations on 6.9-kv delta-connected rural lines, (B) 70 records obtained from 96 installations on the 11.5-kv delta-connected rural lines, and (C) 86 records obtained from 81 installations on the 11.95-kv star-connected rural lines of the Georgia Power Company

Figs. 7 to 9. Comparison of records obtained on different systems

Curves show number of years at a given arrester location that may be expected to elapse before a current of at least the magnitude shown by the abscissa will pass through the arrester

few installations that were not interconnected, and there were so few cases where protection of apparatus was not obtained, that no conclusions could be drawn. It may be that data to be obtained during the continuation of this investigation will make possible definite conclusions regarding this point.

Effect of System Voltage. Figure 7 compares the results from the 4 kv rural circuits of the Commonwealth Edison Company with those from the 4.8 kv rural circuits of the Detroit Edison Company. Although the Chicago results are from grounded neutral circuits while in Detroit the primary circuit is connected in delta, it is believed that the decreased "expectancy" in Detroit, which means more records per year, is probably attributable to greater exposure rather than the type of circuit employed. The Chicago installations, although they have been classified as rural, are probably in more urban territory than the other installations in this classification. Comparisons of this type between different locations are of very doubtful value at best, because of the great variation that is likely to exist in storm severity and number of storms. The United States Weather Bureau reported 82 thunderstorms in the Chicago area during the period of this investigation, compared with 36 in the Detroit area. The number of thunderstorms of course is not in itself a direct measure of the lightning severity to which distribution lines are subjected.

A similar comparison is made between the urban results from 252 installations on the 4-kv grounded-neutral system of the Commonwealth Edison Company and those from 298 installations on the 4-kv star-connected ungrounded circuits of the Edison Electric Illuminating Company of Boston (figure 8). Here again, there is probably considerable difference in the type of territory. The Boston installations are in suburban districts that are not built up to the same extent as the urban districts in Chicago with which they are compared. There were only 18 thunderstorms in the Boston area compared with the 82 in Chicago.

The results from lines of different voltage ratings in Georgia offer a better comparison, being all on the same system, although a considerable difference in storm severity probably exists because of the large territory covered. The Weather Bureau at Atlanta reported 69 thunderstorms during this investigation. The data, shown in figure 9, are all from rural installations. Since the number of installations were 74, 96, and 81, respectively, for the 6.9, 11.5, and 11.95 kv circuits, the data have about equal weight from the point of view of equality of chance. The 2 11 kv expectancy curves differ by a ratio of approximately 2 to 1 with insulation levels and types of construction approximately the same.

Considering the results of the 3 circuits together, no conclusion can be drawn with reference to circuit voltage. More data over a longer period of time will help to average out the effect of local storms which apparently give one circuit rating a more severe duty than some other.

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Lightning Protection of Distribution Transformers

Data on the results of lightning protection for distribution transformers on the system of the Georgia Power Company have been compiled, to determine the improvement resulting from changes which have been made, particularly the interconnection of the ground leads of the primary arrester with the transformer secondary neutral. The data indicate that such interconnection has not produced all the benefits expected. The experience with lightning protection is presented in an impartial manner, and without attempting to offer a solution of existing problems.

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THE system of the Georgia Power Company covering almost the entire State of Georgia, is exposed to lightning practically every month in the year. Transformer and lightning arrester losses have been higher than reported in other sections of the country, and a careful study is being made in an effort to find out what remedies can be applied.

In 1932, when interconnection of the ground lead of the primary arrester with the transformer secondary neutral came into prominence, it seemed that the answer had been found. Very careful investigations were made, and after full consideration it was decided to interconnect grounds as quickly as possible. However, it was late in 1932 before the work could be started, and comparatively few installations were made before the 1933 lightning season.

The results for 1933 seemed to indicate a marked improvement. There were practically no failures of interconnected transformers, and very few fuses blown. With such encouraging results it was expected that, as further interconnection was made, the good record would continue.

At the beginning of the 1934 season, approximately $^1/_2$ of the transformers were protected by interconnected lightning arresters. The season was one of the worst in many years; not only was there more lightning, but it was more severe. Transformers failed, fuses blew, and arresters were blown off the line. Naturally, an effort was made to investigate each case and determine the cause of failure. In most cases, the reason for the failure could be found, but in too many cases there was no apparent reason.

The work of interconnection was continued, and at the beginning of the 1935 season approximately 80 per cent of the arresters were interconnected. This year there have not been as many failures, but it is felt that there have been too many. This is evident from the curves of figure 3. These curves do not indicate a very marked or definite improvement in the operation of the system as a whole.

Considerable Data Collected

Various studies have been made—weather bureau reports have been carefully analyzed to see if any relation existed between failures; storm days, rainy days, temperature, and even wind conditions were

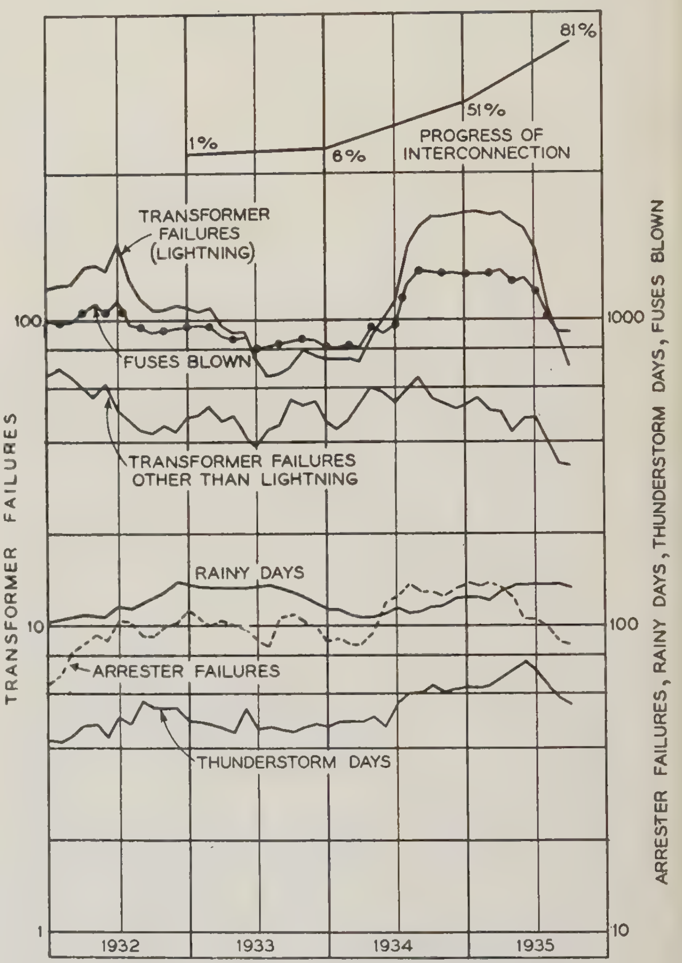

Fig. 1. Relation between weather conditions and lightning troubles

Figures are for the 12 months ending on the dates shown; Atlanta division only

tabulated. There seems to be only one relation, and that is with lightning days. The greater the number of days with lightning the greater the number of failures, and apparently the severity increased with the number of storm days.

There seems to be a slight inverse relation between

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rainy days and failures, and this is shown by the curves given in figure 1. These curves are made up of a total of 12 months, ending with the month plotted. Therefore, variations from month to month are smoothed out and a much more regular curve obtained.

Referring again to figure 1, it will be noted that in 1933 there were about 130 rainy days, while in 1934 this figure dropped down to 110 to 120, and in 1935 back to over 130. It is an old saying that a thunderstorm coming before a rain will cause a great deal more damage than one following a rain, the explanation being that the rain decreases the resistance of trees, buildings, and other high objects and thus forms a drain to ground lessening the possibility of building up potentials in the clouds, and also the rain in falling transfers part of the cloud mass charge to earth. If this reasoning is true, then a lightning season with very few rainy days might be expected to be more severe than one with a greater number.

Data are given in table I for the entire system and for the Atlanta division for the years 1932 to 1935, inclusive. Except during the 9 months of 1935, data with reference to the performance of interconnected arrester are incomplete. However, for the entire company in 1934, 1.7 per cent of the transformers

Fig. 2. Relation between thunderstorm days and circuit outages

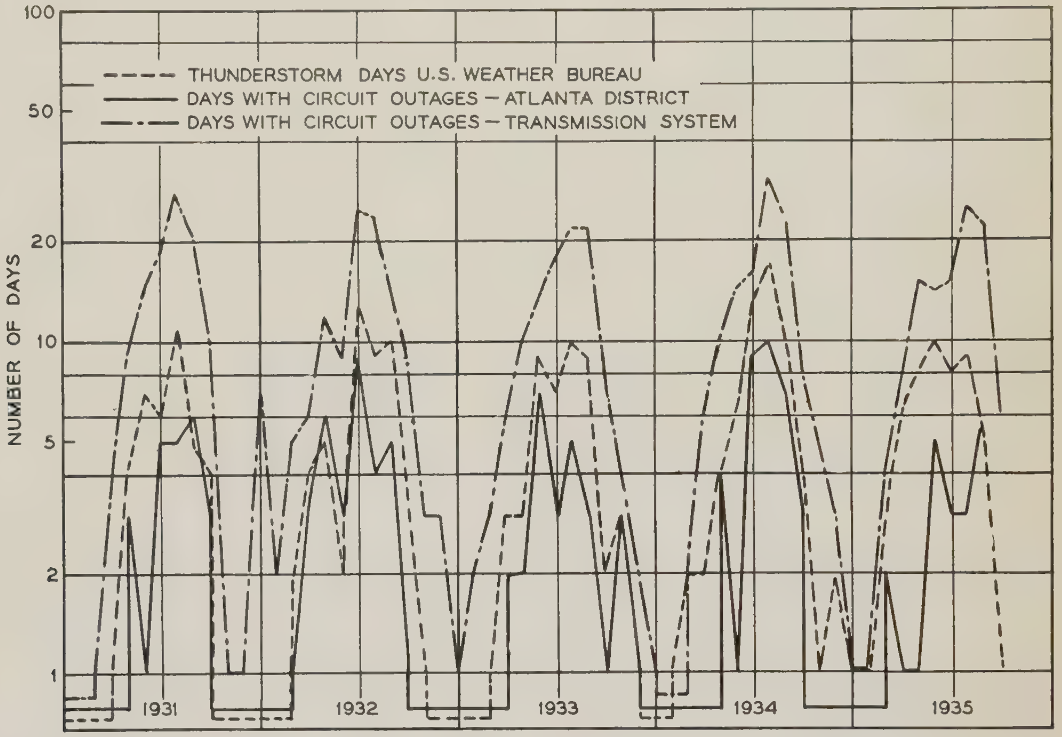

Table I—Lightning Troubles

	Entire Company				Atlanta Division			
	1932	1933	1934	1935 (9 Mo.)	1932	1933	1934	1935 (9 Mo.)
Days with circuit outages	113	112	116	110	32	27	36	22
Total transformers	18,507	18,628	18,190	18,612	7,516	7,578	7,314	7,600
Total fuses blown (all causes)	4,266	4,092	6,058	3,671	960	819	1,424	818
Per 100 transformers	23.0	21.9	33.3	19.7	12.8	10.8	19.5	10.8
Transformer failures (lightning)	317	205	462	205	108	76	214	61
Per cent	1.71	1.10	2.54	1.10	1.44	1.00	2.93	0.80
Arrester failures	279	267	665	202	111	89	138	70
Per 100 transformers	1.51	1.43	3.66	1.08	1.48	1.18	1.89	0.92
With Interconnection								
No. of transformers *with* interconnected arresters	0	1,000	7,225	14,465	0	500	3,737	6,119
Per cent	0	5.4	39.8	77.8	0	6.6	51.0	80.5
No. of fuses blown (all causes)								529
Per 100 transformers								8.65
Transformer failures (ltg)			123	117			49	29
Per cent			1.70	0.81			1.31	0.47
Arrester failures				129				32
Per 100 transformers				0.89				0.52
Without Interconnection								
No. of transformers *without* interconnected arresters	18,507	17,628	10,965	4,147	7,516	7,078	3,577	1,481
Per cent	100	94.6	60.2	22.2	100	93.4	49.0	19.5
No. of fuses blown (all causes)								289
Per 100 transformers								19.5
Transformer failures (ltg)			339	88			165	32
Per cent			3.09	2.12			4.62	2.15
Arrester failures				73				38
Per 100 transformers				1.76				2.56

Table II—Summary of 1932, 1933, 1934, and 9 Months of 1935—2,300 Volt Overhead Transformer Failures From Lightning

Year	3 Kva	5 Kva	7.5 Kva	10 Kva	15 Kva	25 Kva	37.5 Kva	50 Kva	75 Kva	100 Kva and Over	Total
Entire Company—Number in Service											
1932	3,034	3,916	2,740	2,741	1,818	1,374	427	348	88	66	16,552
1933	2,813	4,114	2,667	2,792	1,915	1,460	468	367	111	98	16,805
1934	2,732	3,965	2,801	2,724	1,815	1,340	437	342	94	73	16,323
1935	2,751	4,088	2,875	2,744	1,852	1,364	437	334	97	80	16,622
Total	11,330	16,083	11,083	11,001	7,400	5,538	1,769	1,391	390	317	66,302
Number of Failures											
1932	85	73	31	33	16	2	0	2	0	1	243
1933	38	43	24	19	13	4	1	1	0	0	143
1934	108	113	49	41	31	14	2	3	0	0	361
1935	54	39	18	24	3	2	0	1	0	0	141
Total	285	268	122	117	63	22	3	7	0	1	888
Failures in Per Cent											
1932	2.47	1.87	1.10	1.20	0.90	0.15	0	0.58	0	0.15	1.47
1933	1.34	1.04	0.90	0.68	0.274	0.214	0.273	0	0	0	0.85
1934	3.95	2.85	1.70	1.50	1.70	1.00	0.50	0.80	0	0	2.21
1935	1.96	0.95	0.63	0.87	0.16	0.15	0	0.30	0	0	0.85
Total	2.52	1.67	1.10	1.06	0.85	0.40	0.17	0.50	0	0.31	1.34
Atlanta Division Only—Number in Service											
1932	1,370	1,468	1,097	1,181	949	793	274	201	38	34	7,516
1933	1,278	1,456	1,084	1,163	908	764	262	193	37	35	7,180
1934	1,192	1,484	1,119	1,170	905	749	267	189	37	38	7,150
1935	1,194	1,601	1,188	1,199	932	763	265	183	37	41	7,403
Total	5,034	6,009	4,488	4,713	3,694	3,069	1,068	766	149	148	29,219
Number of Failures											
1932	27	31	18	17	7	3	0	1	0	0	104
1933	11	22	15	6	10	3	1	1	1	0	70
1934	47	62	30	26	21	9	1	2	0	0	198
1935	18	16	9	13	1	1	0	0	0	0	58
Total	103	131	72	62	39	16	2	4	1	0	430
Failures in Per Cent											
1932	1.96	2.14	1.64	1.43	0.74	0.378	0	0.548	0	0	1.38
1933	0.862	1.51	1.38	0.515	1.10	0.392	0.382	0.52	2.70	0	0.973
1934	3.94	4.17	2.52	2.22	2.32	1.20	0.375	1.06	0	0	2.77
1935	1.50	1.00	0.756	1.08	1.08	0.107	0.131	0	0	0	0.783
Total	2.05	2.18	1.60	1.31	1.05	0.52	0.19	0.52	0.67	0	1.47

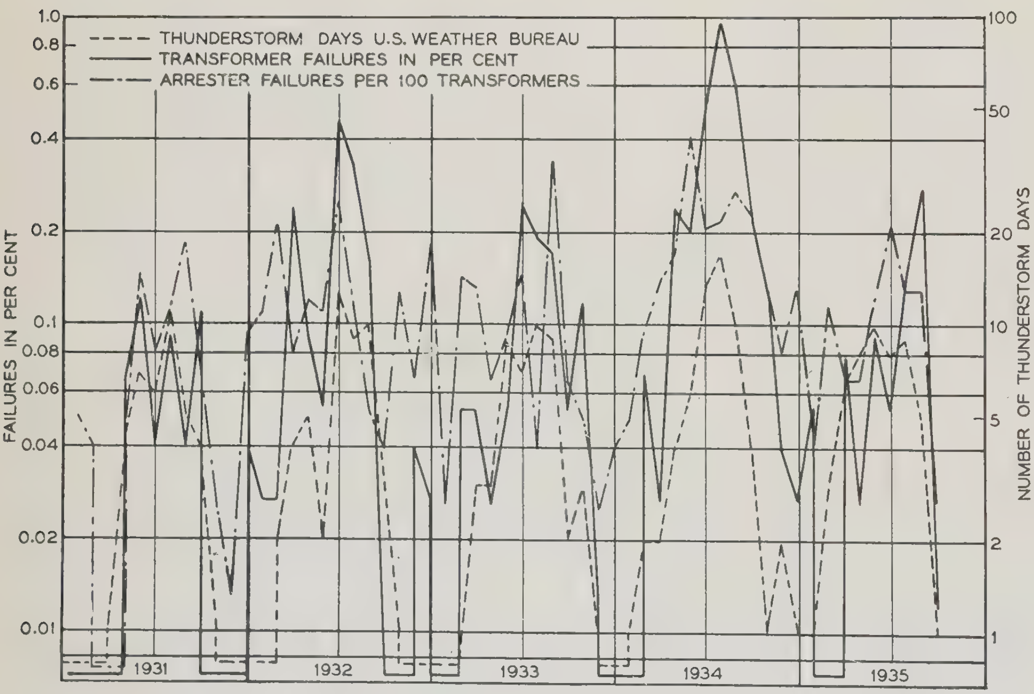

Fig. 3. Relation of thunderstorm days to arrester failures and transformer failures

with interconnected arresters failed, while 3.09 per cent without interconnection failed. For the 9 months of 1935, the percentages were 0.81 and 2.12, respectively. Similar results are obtained for the Atlanta district. These results indicate that the interconnected performance was better by a ratio of somewhat more than 2 to 1. Concerning fuse blowings, a similar result is found for 1935 in the Atlanta district, although fuses blown during lightning storms are not segregated.

Table I also indicates a reduction in the percentage of arrester failures when the arrester is interconnected. Since this represents but 9 months of 1 year, it may not be significant. Of course, with fur-

ther interconnection, the opportunity of further comparison will be lost, it being possible only to compare one year with another, which will be affected by storm severity to a much greater degree.

When making comparisons between interconnected arrester performance and those not interconnected, it is realized that they are not operating under identical storm conditions; in fact, the differences over a state as large as Georgia are likely to be very marked.

Tables II, III, and IV show the record of the past 4 years by voltage class and kilovoltampere rating of transformers. These data show, as shown by other similar tabulations, that in general the smaller transformers in a given voltage class are more susceptible to failure. Presumably, these results are due in part to the age of transformers, their condition, and their size. It is somewhat surprising to note in table II that with the single exception of the 3 kva rating, the percentage of 2,300 volt transformers which failed outside of the Atlanta division is less than inside. When making this comparison attention should be called to the fact that the exposure in the Atlanta district is nearly as bad as in the outlying districts. No explanation has been found for the relatively poorer record in Atlanta.

Attention should also be called to the increase in percentage of troubles with the transformers in the higher voltage ratings, as given in tables III and IV. The data show nearly 5 times as high a percentage failure in 11.5 kv transformers as was found with the 2,300 volt transformers. No good explanation has been found for this as yet, and discussion from others on this point would be helpful.

Lightning Severity

That the severity of lightning increases with the frequency in a given area has been demonstrated by the records obtained from klydonograph records obtained from the Lithonia substation for 1934 and 1935. When the storms were frequent the potentials measured appeared to be greater in magnitude.

Another interesting point on the severity of lightning was brought out by the use of recorders, and that is, the areas high above sea level are more subject to lightning troubles. Although the frequency of storms reported by the U.S. Weather Bureau for the area around Brunswick is higher than for Atlanta, it was found in the studies discussed herein that the mountainous sections have more storms that can be measured than the lowlands of South Georgia. Therefore, the relation between frequency and severity must be confined to a given area.

An interesting comparison of days with lightning

Table III—Summary of 1932, 1933, 1934, and 9 Months of 1935—6,900 Volt Overhead Transformer Failures From Lightning

	3 Kva	5 Kva	7.5 Kva	10 Kva	15 Kva	25 Kva	37.5 Kva	50 Kva	75 Kva	100 Kva and Over	Total
Entire Company—Number in Service											
1932	289	275	108	90	53	55	6	11	14	24	925
1933	344	277	91	73	65	68	13	8	14	24	977
1934	331	322	101	91	65	65	15	8	14	24	1,036
1935	339	340	113	90	76	76	15	10	14	23	1,096
Total	1,303	1,214	413	344	259	264	49	37	56	95	4,034
Number of Failures											
1932	14	18	4	3	2						42
1933	5	10	3	1	1						20
1934	18	22	7			1					48
1935	9	8	3	3		1					24
Total	46	58	17	7	4	2					134
Failures in Per Cent											
1932	4.8	6.5	3.7	3.3	5.7						4.54
1933	1.45	3.62	3.3	1.37	1.54						2.05
1934	5.4	6.7	6.9			1.5					4.64
1935	2.65	2.35	2.65	3.33		1.3					2.20
Total	3.52	4.75	4.1	2.04	1.54	0.75					3.33

Table IV—Summary of 1932, 1933, 1934, and 9 Months of 1935—11,500 Volt Overhead Transformer Failures From Lightning

	2.5 Kva	5 Kva	10 Kva	15 Kva	25 Kva	37.5 Kva	50 Kva	75 Kva	100 Kva and Over	Total
Entire Company—Number in Service										
1932	23	259	46	14	45	11	8	3	10	419
1933		318	53	16	46	16	8	8	7	472
1934	25	337	65	27	55	17	8	7	7	548
1935	24	364	62	28	56	17	8	6	7	572
Total	72	1,278	226	85	202	61	32	24	31	2,011
Number of Failures										
1932	1	25	6							32
1933		34	7							41
1934	3	38	9							50
1935	4	23	8	1						36
Total	8	120	30	1						159
Failures in Per Cent										
1932	4.0	9.8	13.4							7.75
1933		10.8	13.2							8.70
1934	12.0	11.4	14.0							9.00
1935	5.5	6.3	12.9	3.57						6.30
Total	11.1	9.4	13.2	1.17						7.90

is that of circuit outages, shown in figure 2. The thunderstorm days are those reported by the Weather Bureau for Atlanta and naturally there are a great number of storms reported that do not cause outages. The days with outages shown for the transmission system cover the entire state and naturally exceed the storm days reported in Atlanta. In going over these records it is sometimes possible to follow a storm over the state. It may start in North Georgia and continue down the length of the state, taking 2 or 3 days.

Arrester Failure

One of the most difficult problems to solve is that of arrester failure. From the curves and tables it will be noted that failures on this system are high. In checking up on the number of arresters purchased since January 1927 and estimating the number now on the system, it is found that since 1927 almost enough have been purchased to have replaced every arrester. This is certainly true of the 6,900 and 11,500 volt systems.

An old saying of linemen and substation maintenance men is that arresters fail more frequently in areas of high ground resistance. This is contrary to all theory, but a number of cases are known where there was high ground resistance, and where arrester failures have been frequent. The grounds have

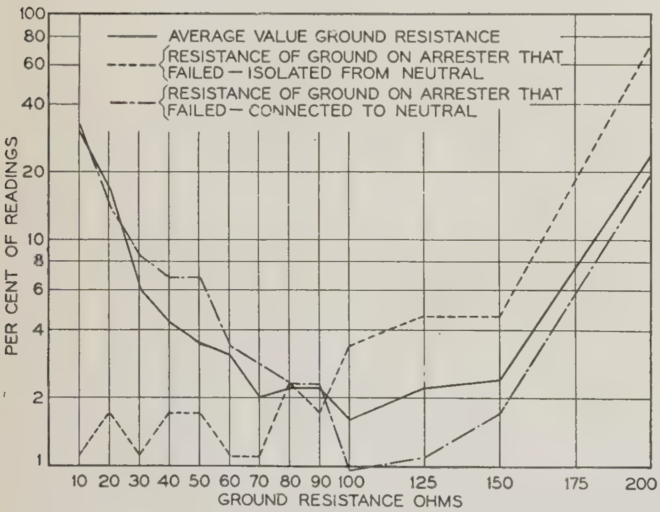

Fig. 4. Relation between ground resistance and arrester failures

been treated to lower the resistance and the number of arresters failing has decreased. These cases are too numerous to pass by lightly, and indicate that something is lacking in the theory of arrester performance.

In an effort to find the answer 176 cases of arrester failure were picked out at random and the resistance of the grounds was measured. The resistance was measured with the arrester ground disconnected from the neutral, and then measured with the ground connected to the neutral. The results are shown in figure 4, and it is apparent that there are very few individual grounds with a resistance under 100 ohms, but this number is materially increased by connecting the arrester ground to the secondary neutral.

On this curve is plotted also an average value of ground resistance, made up from some 800 different tests. While this small number will not reflect the true picture of the entire power system, it should be indicative of what might be expected.

If it is assumed that the arresters are destroyed by surge currents the single electrode resistance would be expected to be the determining factor, as the surge impedance of one span of neutral would be so high that there would be very little benefit from it. Yet it is found that over 70 per cent of these failures have isolated ground resistance of over 200 ohms, and the lineman's argument would be correct.

Table V—Analysis of 176 Cases of Arrester Failure

	3 Kv	6 Kv	9 Kv	12 and 15 Kv	Total
Number of arrester failures	112	2	32	30	176
per 100 transformers	0.67	1.3	2.92	5.25	0.93
Ground resistance—isolated	170	110	178	169	171
Ground resistance—combined	57.50	100	86	72	65

If on the other hand it is assumed that leakage current and power follow current destroy the arresters, the combined resistance would be the one to consider, and it is found that this curve follows very closely the curve of average values obtained in this study. This would indicate that taken on a percentage basis the failure rate for each value of ground resistance is constant. Further analysis of these 176 failures gives the results shown in table V. From these figures it would seem that ground resistance does not influence arrester failures.

Location of Arrester

On transformers with the neutral interconnected, the arresters have been placed on the load side of the fuse. There were several reasons for doing this, although it was expected that there would be a few more outages. However, the number of fuses blown has been considerably higher than expected, and seems to indicate something lacking in the theory of interconnection.

In view of the voltages that can be expected on distribution lines, it does not seem possible to have frequent fuse blowing from surge currents. The amount of power current flowing through the arrester during discharge should not be enough to cause fuses to blow. Yet they are being blown so frequently that the arresters are being changed so as to be ahead of the fuse, to stop these interruptions.

The arrester was mounted on the transformer "kick" arm as this brought the arrester close to the equipment to be protected. The ground lead was brought across the arm to the pole and then down to the ground. The tie to the neutral was connected just under the arm and run up the pole to the secon-

dary neutral. The neutral lead of the transformer was connected to this secondary neutral about 18 inches from the pole. Thus there was a rather long run from the arrester ground terminal to the neutral lead of the transformer. On 6,900 and 11,500 volt construction this distance was on the order of 12 or 14 feet.

It is impossible to say just what the surge impedance of this lead would be, but it is felt that it is high enough to cause in some cases an impedance drop to build up that will flash over the leads and bushings before the potentials are equalized. Therefore, the specifications are being changed, the arrester being placed on the hanger arm, and the neutral tie being carried directly across the top of the transformer case.

Causes of Transformer Failure

The failures of interconnected transformers have been investigated wherever possible, and a great number of contributory conditions have been found. Most important of these are the following:

1. Transformers having bad leads and bushings.
2. Arresters that looked good on casual inspection but were found to be bad on closer inspection or on breaking.
3. Close clearances in small transformers.
4. Evidence of a direct stroke of lightning in the immediate vicinity of the transformer.
5. The tie between the arrester ground and neutral seemed too long and probably its impedance was of such value that the transformer flashed over before the secondary winding and case were brought up to surge potential. This point has not been proved yet, and some tests under laboratory conditions may be made to determine what effect this will have.
6. The ability of the transformer case to float, especially on a wet pine pole was studied very carefully, and it is believed the case should be tied in to the circuit directly or through a gap. However, this practice has not been started except on 6,900 volts and higher.

Remedies

In order to overcome the above conditions, the following changes in methods have been made:

1. The test voltage has been raised on all transformers, both new and rebuilt, to 75 per cent of the new A.I.E.E. test voltages.
2. When leads and bushings are replaced, the transformer is removed to the shop and new bushing and lead assemblies put in.
3. Small cores and coils have been put in larger cases, i. e., a 5 kva unit put in a 7.5 kva case.
4. New type cases were purchased for 11,500 volt units and the old cases used for lower voltage units.
5. The design of the transformer structure has been changed placing the arrester on the hanger arm and tying the grounds together by a short tie directly across the top of the transformer to the neutral.
6. The arrester ground is being tied to the transformer case, on all 6,900, 11,500 and 13,800 volt transformers, thus making the neutral, case, and arrester-ground common.

This paper is written to give others the benefit of experience on one power system, and is not offered with the idea that solutions to existing difficulties have been found. Some gain has been made through interconnection, and some of the changes which are to be made in the transformers and proetctive arrangement will, it is hoped, lead to improvement.

A New Trigger Circuit for Closing a Switch

An electronic device is described for controlling the closing of a relay or switch at a predetermined point on the wave form of an a-c source. Current for closing the relay is controlled by a gas filled triode, the firing of which is obtained by the distorted wave of a multivibrator. The output of the multivibrator is made to change phase with reference to the a-c voltage wave. The device is useful for the study of transients.

By
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SEVERAL devices have been designed for closing (or opening) a switch or contactor at a predetermined point on the voltage or current wave form. Thus, Kennelly and Nabeshima[1] used a commutator revolved by a synchronous motor, obtaining the phase shift by turning of contactors. H. R. Reed[2] used a similar device. A synchronous motor, however, has inertia and is subject to hunting which may affect the time of closing of the switch by several degrees. W. Orkney[3] used a gas or vapor filled electronic tube, the firing of which was controlled by a sinusoidal wave. In one of Orkney's circuits, the firing was obtained at the peak of the sinusoidal wave where it is changing at its slowest rate; hence the results could not be reproduced closer than a few degrees. The circuit herein described uses an argon-filled 3-element electronic tube and the firing is obtained by superimposing a wave, having a very steep front and well defined peak, on the steady grid bias. The results obtained can be reproduced to within a fraction of a degree in terms of 60 cycle frequency.

Description of Apparatus

The apparatus used consists of 3 principal parts. First, a gas filled triode, whose anode current controls the magnet or solenoid of the relay or contactor. In the present experiments, an argon filled tube was used, but any gas-filled grid-controlled tube will operate as well. Second, a multivibrator is used,

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The author acknowledges the assistance of Dr. F. M. Sebast and Dr. G. R. Town, both of Rensselaer Polytechnic Institute.

1. For all numbered references, see list at end of paper.

whose output is controlled by an a-c voltage from the same mains used on the contactor and load. The output of the multivibrator is added in series with the steady grid bias. The peak of the multivibrator wave initiates the discharge. Third, a phase shifter or similar device is used to produce a relative shift in phase between the multivibrator control and the a-c supply to the switch or contactor. The diagram of connections is given in figure 1, but before proceeding with an explanation of the method of operation, it will be best to describe the individual parts more in detail.

The multivibrator[4] is a well known device used in the radio art to obtain a wave form very rich in harmonics, and as such it is used extensively for frequency multiplication. Briefly, it consists of a 2-stage capacity-resistance coupled amplifier, the output of one vacuum tube being fed back to the grid circuit of the other as shown in figure 1. The output of the second tube has the proper phase relation to the input of the first; thus the device will oscillate of its own accord. The wave form obtained has, in general, a very steep front[5] and is more or less rectangular in shape. With the tubes and values shown on figure 1, it was possible to obtain a wave shape with a very sharp peak, although for the purpose on hand, this extreme was not necessary. The period of oscillation is roughly of the order given by the product of the capacity of the capacitor C_1 and the resistance r_1. However, if one of the plate resistances is made very much larger than the other, it is possible, by the introduction of a small controlling voltage into the common plate lead, to bring the natural frequency of the multivibrator into exact synchronism with that of the controlling voltage, provided the natural frequency of the multivibrator is not far from that of the control. It has also been found[6] that the phase relation between the controlling voltage and the output is constant and permanent for a given set up. It is this feature of the multivibrator that makes it useful in the present device. Another advantage is that the wave front of the output is very steep, almost perpendicular. Dye[5] states that even in terms of a frequency of 1,000 cycles per second, the change from zero to maximum takes place almost instantaneously. Figure 2 bears out this statement.

The phase of the multivibrator output with respect to the a-c supply voltage can be changed by various methods. In figure 1, a 3 phase shifter is used, which permits 360 degree change. However, for most purposes, a 90 degree phase shift is perhaps all that is necessary. Changing the grid resistance r_1, figure 1, causes a phase shift of about 45 degrees. Further change can be obtained by use of a capacitor in parallel with a variable resistance in the control circuit; this is a well known device.

Time Delay

The multivibrator output is impressed upon the grid of the argon filled triode as shown in figure 1, and again, diagrammatically, in figure 3. Since the voltage applied to the anode of the triode is direct current the tube should fire whenever the grid potential reaches the critical point, which, for the case shown, is about -4 volts. When the triode fires, the relay or contactor is closed, and the transient is initiated on the load. In order to obtain a photographic record with an ordinary oscillograph, it is necessary to introduce a time delay to give time for the oscillograph shutter to open. This time delay is obtained by the well known device shown on the figures. With the switch S closed, a steady bias of approximately -16 volts is impressed on the grid. As shown on figure 3, the peaks of the multivibrator output (in series with the steady bias) are too low to

Fig. 2. Distorted wave of multivibrator output. Note steep front

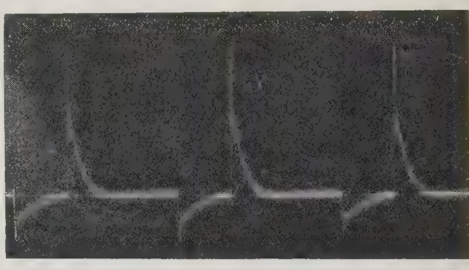
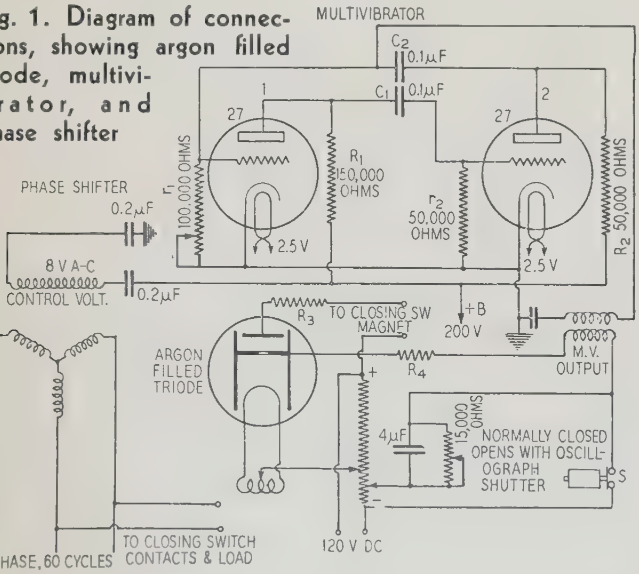


Fig. 1. Diagram of connections, showing argon filled triode, multivibrator, and phase shifter



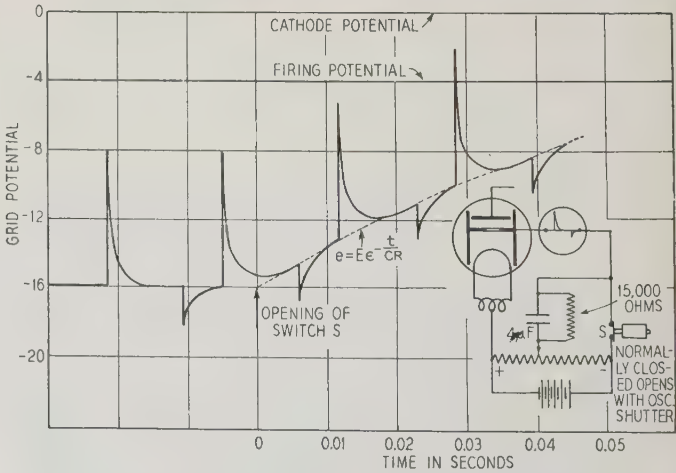


Fig. 3. Action of the time delay device. When S is opened, the steady bias is shifted, but the grid potential does not change until the capacitor has discharged

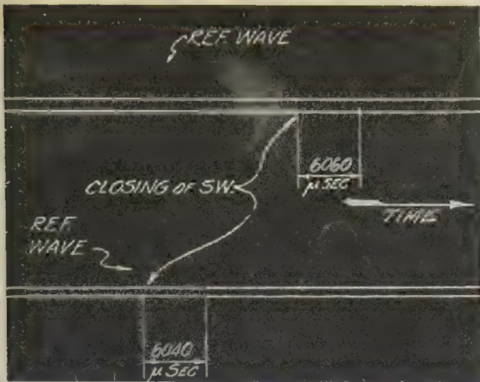
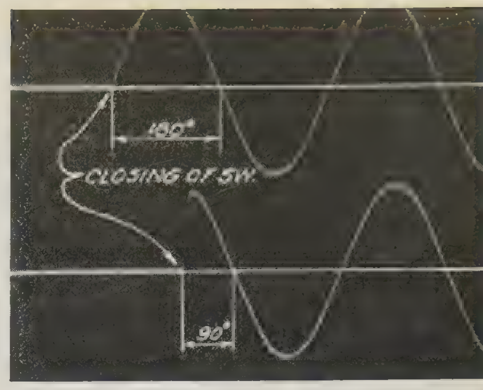


Fig. 4. Oscillograms of transients on a resistive load using the same setting of apparatus. Note accuracy with which results can be duplicated

Fig. 5. Oscillograms of transients on a resistive load, using 2 different settings, 90 degrees apart



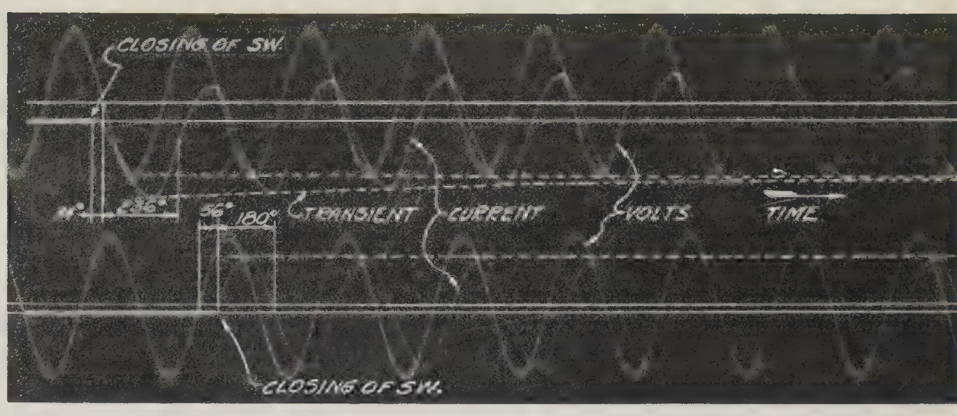


Fig. 6. Oscillograms of transients on an inductive resistance load at 2 preselected points 90 degrees apart. Note the small resistance transient in one case, and large inductive transient in the other

cause firing. When the shutter trigger on the oscillograph is tripped, the switch S is opened, and the bias is changed to the -4 volt point, but before the grid can assume this potential, the capacitor has to discharge through the resistor so that the peaks climb slowly toward the firing potential. As shown on the figure, the first peak after opening of S does not quite reach the firing point, but the second does. Now, due to the very steep wave front, a change in grid bias will not affect the point of firing with reference to the multivibrator wave, although it will change the time delay. The peaks of the multivibrator wave bear a fixed relation to the a-c supply voltage; hence, it is possible to obtain closing of the switch at a given point of the wave. The ionization time of the argon filled triode used is of the order of 10 microseconds, which, in terms of 60 cycle frequency, is only a few tenths of a degree, so that on this score, the error is small. Greater errors are encountered in the constancy of the closing time of the relay or contactor.

Method of Operation, and Results

Referring to figure 1, the solenoid or magnet of the contactor is placed in series with the plate of the triode, and the protective resistor R_3. The phase shifter is set at a given point, and a preliminary oscillogram is taken. The point at which the contactor closes in relation to the voltage wave is determined from the oscillogram and compared to the phase shifter position. Thereafter, if the phase shifter head is calibrated in degrees, it is possible to change the position of closing to any predetermined point.

Some of the oscillograms taken are given. Figure 4 shows 2 oscillograms taken with a resistive load using the same setting of the apparatus, and illustrates the accuracy with which results can be reproduced. Although on this figure time is given in microseconds, it is not claimed that measurements closer than the third significant figure are possible. Many other similar oscillograms show that the time of closing can be duplicated within 20 to 30 microseconds which corresponds to less than a degree at 60 cycle frequency. See also figure 5. Figure 6 shows 2 oscillograms of an inductive resistance, taken at 2 preselected points 90 degrees apart. One shows only the small resistance transient; the other a large inductive transient. The fact that it was possible to take these 2 oscillograms on the same film gives conclusive evidence of the reliability of the apparatus and the accuracy with which results can be predicted.

In addition to the possibility of obtaining transients for subsequent study of switching operations, the device should find useful applications for closing or opening a switch so as to minimize transients or destructive arcing.

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2. Contactor Closes Circuit at Selected Point on Wave Form, H. R. Reed. *Elec. World*, v. 100, Oct. 22, 1932, p. 563–4.

3. Development of Apparatus for the Control of an Oscillograph in Recording Transients, W. Orkney. Thesis, 1934. On file in the library of Rensselaer Polytechnic Institute.

4. Mésure en Valeur Absolve de Périodes, des Oscillators Electriques de Haute Fréquence, H. Abraham and E. Bloch. *Ann. de Phys.*, v. 11–12, 1919, p. 237–302.

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6. A Convenient Method for Referring Secondary Frequency Standards to a Standard Time Interval, L. M. Hull and J. K. Clapp. I.R.E. *Proc.*, v. 17, 1929, p. 252–71.

News

Of Institute and Related Activities

Technical Program Announced for the A.I.E.E. Winter Convention

THE TECHNICAL program for the A.I.E.E. winter convention which will be held in the Engineering Societies Building, 33 West 39th Street, New York, N. Y., January 28–31, 1936, is, as usual, of broad scope and timely interest. The convention will convene on a Tuesday and technical sessions will be held both morning and afternoon for the first 3 days. Arrangements are being made for the smoker on Tuesday evening, which is expected to at least duplicate the noteworthy success of the last winter convention smoker. Wednesday evening the Edison Medal presentation will take place and on Thursday evening the dinner-dance will be held at the well-known Hotel Plaza. Friday will be devoted exclusively to inspection trips to interesting places in the city and the vicinity.

The well-balanced program will be interspersed with committee meetings, of importance to many members. Also, arrangements are being made for a luncheon meeting of the committee on education and the Student Branch counselors on Wednesday, January 29. While the daily business programs are quite concentrated, ample opportunities through the days and evenings will occur to renew acquaintanceships and converse with friends. Plan now to attend the convention and keep abreast of the developments in the profession. Details of the various features now being arranged will be announced in the January 1936 issue of ELECTRICAL ENGINEERING. The technical program, however, is given in this article.

Technical Papers

Thirteen technical sessions and one technical conference have been scheduled to bring forth a number of developments in specialized fields. Several of the papers for these sessions are of international importance, particularly the adoption by the International Electrotechnical Commission of the meter-kilogram-second system of units, the story of which will be told by Dr. A. E. Kennelly. Also, 2 papers from France will treat the developments in the electrochemical and electrometallurgical industries in that country. One of these papers will describe the electric furnace with carbon radiator, which has been perfected to a high degree in France.

Another group of papers sure to be of outstanding interest will be presented in the protective devices session. Several of these papers will present data obtained from this year's lightning season in various sections of the country. Data will be included on lightning arrester performance and the protection of distribution transformers, some of it the first presented in respect to the interconnection of the primary and secondary neutrals.

At 1 or 2 other sessions and the conference on electric welding, demonstrations of electrical phenomena by means of high speed motion pictures will play an important part. In each case the technique of obtaining the pictures will be explained. The latest design practices in the development of synchronous machinery as well as recent studies in commutation will be presented at 2 sessions on electrical machinery. Many other papers of interest appear on the program.

The schedule for the 13 sessions and the papers to be presented at each session are given in the accompanying columns. For the papers which have been published, reference to the issue and page is given after each title. Members who wish to follow the presentations in detail and discuss papers should take their issues with them or prepare their discussions in advance. The conference on electric welding will be devoted to demonstrations without publication of papers or the discussions.

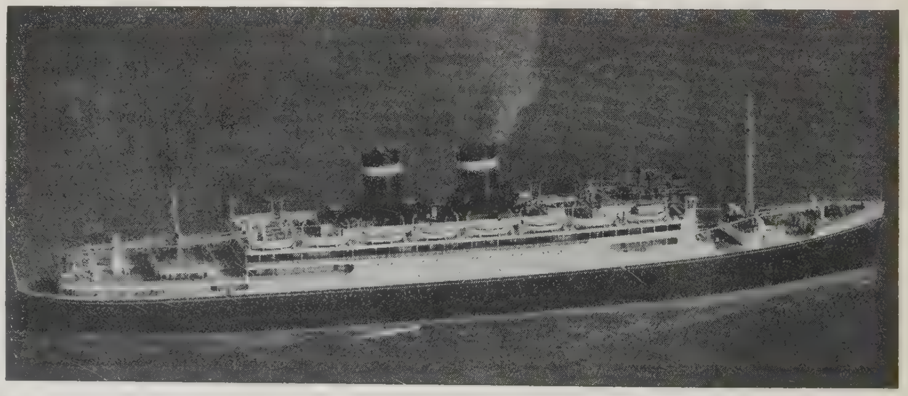
Rules on Presenting and Discussing Papers

At some of the technical sessions, a few papers may be presented only by title. This will permit the devotion of more time to discussion. At other sessions, papers will be presented in abstract, 10 minutes being allowed for each paper unless otherwise arranged, or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Authors will be notified officially in each case about one month in advance.

Any member is free to discuss any paper when the meeting is thrown open for general discussion. Usually 5 minutes are allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted to have a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser is to step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussion to be considered for publication must be submitted, typed double spaced, in triplicate to C. S. Rich, secretary of the technical program committee, A.I.E.E. headquarters, 33 West 39th St., New York, N. Y., on or before Feb. 14, 1936. Discussion received after this date will not be accepted.



New York, busiest port of the United States, offers numerous attractions. Among the many inspection trips which will be made available to Institute members during the forthcoming winter convention in New York, January 28–31, 1936, is a visit to a modern steamship. Shown here is the "S.S. California" of the Panama-Pacific Lines. Details of inspection trips will be announced in the January 1936 issue

Tentative Technical Program

In this program, reference to the issue and, in so far as possible, to the page in ELECTRICAL ENGINEERING, is given for all papers which are being published up to and including this issue.

Tuesday, January 28

9:00 a.m.—Registration

10:00 a.m.—Opening of Convention

10:30 a.m.—Communication

APPLICATIONS OF A PHOTOELECTRIC CELL, A. H. Lamb, Weston Electrical Instrument Corp. Nov. issue, p. 1186–95

ANODE MATERIALS FOR HIGH VACUUM TUBES, E. E. Spitzer, RCA Manufacturing Co., Inc. Nov. issue, p. 1246–51

A CABLE CODE TRANSLATOR SYSTEM, A. F. Connery, The Commercial Cable Co. Nov. issue, p. 1162–6

MEASUREMENT OF TELEPHONE NOISE AND POWER WAVE SHAPE, J. M. Barstow and P. W. Blye, Bell Telephone Laboratories, Inc., and H. E. Kent, Edison Electric Institute. Dec. issue, p. 1307–15

10:30 a.m.—Electrophysics—I

I.E.C. ADOPTS MKS SYSTEM OF UNITS, A. E. Kennelly, Harvard University. Dec. issue, p. 1373–84

PARALLEL INVERTER WITH RESISTANCE LOAD, C. F. Wagner, Westinghouse Electric and Mfg. Co. Nov. issue, p. 1227–35

2:00 p.m.—Instruments and Measurements

HIGH SPEED MOTION PICTURES, H. E. Edgerton, Massachusetts Institute of Technology. Feb. issue, p. 149–53

BRIDGE MEASUREMENT OF ELECTROMAGNETIC FORCES, A. C. Seletzky and G. L. Priday, Case School of Applied Science. Nov. issue, p. 1149–52

POWER AND ENERGY—POSITIVE AND NEGATIVE, L. A. Doggett and H. I. Tarpley, Pennsylvania State College. Nov. issue, p. 1204–9

THE COMPENSATED ELECTROTHERMIC AMMETER, W. N. Goodwin, Jr., Weston Electrical Instrument Corp. Scheduled for Jan. 1936 issue

2:00 p.m.—Electrophysics—II

EARTH RESISTIVITY AND GEOLOGICAL STRUCTURE, R. H. Card, American Telephone and Telegraph Co. Nov. issue, p. 1153–61

CURRENT HARMONICS IN NONLINEAR RESISTANCE CIRCUITS, T. D. Owens, Case School of Applied Science. Oct. issue, p. 1055–7

A GENERALIZED INFINITE INTEGRAL THEOREM, M. G. Malti, Cornell University. Nov. issue, p. 1222–7

EFFECT OF TOTAL VOLTAGE ON BREAKDOWN IN VACUUM, H. W. Anderson, Iowa State College. Dec. issue, p. 1315–20

TWO METHODS OF MAPPING FLUX LINES, F. W. Godsey, Jr., Sprague Specialties Co. Oct. issue, p. 1032–6

* These papers may be presented but they have not been accepted for publication at the time of going to press. Of these papers, those which are accepted will, in so far as is possible, be published in the January 1936 issue.

Wednesday, January 29

10:00 a.m.—Power Transmission

ECONOMICAL LOADING OF UNDERGROUND CABLES, E. A. Church, Edison Electric Illuminating Co. of Boston. Nov. issue, p. 1166–72

THE PYROCHEMICAL BEHAVIOR OF CELLULOSE INSULATION, F. M. Clark, General Electric Co. Oct. issue, p. 1088–94

RESOLUTION OF SURGES INTO MULTIVELOCITY COMPONENTS, L. V. Bewley, General Electric Co. Nov. issue, p. 1199–1203

CORONA LOSSES AT 230 KV WITH ONE CONDUCTOR GROUNDED, J. C. Carroll, Stanford University, and D. M. Simmons, General Cable Corp. Aug. issue, p. 846–7

LIGHTNING CURRENTS IN FIELD AND LABORATORY, P. L. Bellaschi, Westinghouse Electric and Mfg. Co. Aug. issue, p. 837–43

10:00 a.m.—Synchronous and Other Machines

"ANGLE SWITCHING" OF SYNCHRONOUS MOTORS, C. C. Shutt and J. W. Dawson, Westinghouse Electric and Mfg. Co. Nov. issue, p. 1191–5

LOAD LOSSES IN SALIENT POLE SYNCHRONOUS MACHINES, E. I. Pollard, Westinghouse Electric and Mfg. Co. Dec. issue, p. 1332–40

PULL-IN CHARACTERISTICS OF SYNCHRONOUS MOTORS, D. R. Shoults, S. B. Crary, Jr., and A. H. Lauder, General Electric Co. Dec. issue, p. 1385–95

*MECHANICAL AND ELECTRICAL PROBLEMS INVOLVED IN THE DESIGN AND CONSTRUCTION OF LARGE TURBINE GENERATORS, C. M. Laffoon, M. D. Ross, and L. A. Kilgore, Westinghouse Electric and Mfg. Co.

SEGREGATION OF LOSSES IN SINGLE PHASE INDUCTION MOTORS, C. G. Veinott, Westinghouse Electric and Mfg. Co. Dec. issue, p. 1302–6

10:00 a.m.—Electrochemistry and Electrometallurgy

THE ENGINEERING DEVELOPMENT OF ELECTROCHEMISTRY AND ELECTROMETALLURGY, Paul Bunet, Paris, France. Dec. issue, p. 1320–31

INDUCTION HEATING AT LOW TEMPERATURES, E. L. Bailey, Chrysler Motor Corp. Nov. issue, p. 1210–2

ELECTRIC FURNACES WITH CARBON RADIATOR, Henri George, Saint-Gobain Co. Nov. issue, p. 1195–9

POWER COMPANY SERVICE TO ARC FURNACES, L. W. Clark, The Detroit Edison Co. Nov. issue, p. 1173–8

2:00 p.m.—Symposium on Magnetic Materials

PRESENT STATUS OF FERROMAGNETIC THEORY, R. M. Bozorth, Bell Telephone Laboratories, Inc. Nov. issue, p. 1251–61

SILICON STEEL IN COMMUNICATION EQUIPMENT, C. H. Crawford and E. J. Thomas, General Electric Co. Dec. issue, p. 1348–53

CHARACTERISTICS OF PERMANENT MAGNET MATERIALS, C. S. Williams, Westinghouse Electric and Mfg. Co. Scheduled for Jan. 1936 issue

MAGNETIC ALLOYS OF IRON, NICKEL, AND COBALT, G. W. Elmen, Bell Telephone Laboratories, Inc. Dec. issue, p. 1292–9

HIGH POWER AUDIO TRANSFORMER FOR CLASS B AMPLIFICATION, J. F. Peters, Westinghouse Electric and Mfg. Co. Scheduled for Jan. 1936 issue

IMPROVEMENTS IN COMMUNICATION TRANSFORMERS, A. G. Ganz and A. G. Laird, Bell Telephone Laboratories, Inc. Dec. issue, p. 1367–73

2:00 p.m.—Electrical Machinery

FLASHING OF RAILWAY MOTORS CAUSED BY BRUSH JUMPING, R. E. Hellmund, Westinghouse Electric and Mfg. Co. Nov. issue, p. 1178–85

ELECTRICAL BRUSH WEAR, V. P. Hessler, Iowa State College. Oct. issue, p. 1050–4

A STATIC THERMIONIC TUBE FREQUENCY CHANGER, A. Schmidt, Jr., and R. C. Griffith, General Electric Co. Oct. issue, p. 1063–7

SELF EXCITATION OF A FREQUENCY CONVERTER, Oscar Hess, Belmont, Mass. Dec. issue, p. 1359–66

VIBRATORILY COMMUTATED STATIONARY CONVERSION, G. T. Southgate, Consulting Engineer. Nov. issue, p. 1213–21

BREAKDOWN CURVE FOR SOLID INSULATION, V. M. Montsinger, General Electric Co. Dec. issue, p. 1300–1

2:00 p.m.—Automatic Stations

SYSTEM POWER DISPATCHING BY REMOTE METERING AND AUTOMATIC LOAD CONTROL, J. T. Logan, Georgia Power Co. Scheduled for Jan. 1936 issue

*SUPERVISORY CONTROL AND REMOTE METERING ON THE PENNSYLVANIA RAILROAD ELECTRIFICATION, J. V. B. Duer, Pennsylvania Railroad.

*AUTOMATIC SWITCHGEAR FOR MERCURY ARC RECTIFIERS, H. Bany, General Electric Co., and M. E. Reagan, Westinghouse Electric and Mfg. Co.

APPLICATION OF SUPERVISORY CONTROL EQUIPMENT, S. A. Canariis, Bureau of Water, City of Pittsburgh. Scheduled for Jan. 1936 issue

Thursday, January 30

10:00 a.m.—Symposium on Modernization of Distribution Systems

MODERNIZATION OF HIGH AND MEDIUM VOLTAGE TRANSMISSION LINES, Lightning and Insulating Subcommittee. Scheduled for Jan. 1936 issue

*MODERNIZATION OF DISTRIBUTION, H. P. Seelye, The Detroit Edison Co.

*MODERNIZATION OF RELAY SYSTEMS ON TRANSMISSION NETWORKS, C. A. Muller and H. E. Turner, American Gas and Electric Co.

*MODERNIZATION OF LIGHTNING PROTECTION EQUIPMENT—TRANSFORMER PROTECTION, Transformer Subcommittee and Lightning Arrester Subcommittee.

10:00 a.m.—Transportation

THE SPEED-TIME ELECTROGRAPH, P. C. Cromwell, New York University. Sept. issue, p. 923–30

THE "COMET"—A DIESEL ELECTRIC UNIT TRAIN, A. H. Candee, Westinghouse Electric and Mfg. Co. Nov. issue, p. 1240–5

THE "BIWAY" SYSTEM OF ELECTRIC PLATFORMS FOR MASS TRANSIT, N. W. Storer, Westinghouse Electric and Mfg. Co. Dec. issue, p. 1340–7

2:00 p.m.—Protective Devices

PILOT WIRE RELAY PROTECTION, E. E. George and W. R. Brownlee, Tennessee Electric Power Co. Nov. issue, p. 1262–9

LIGHTNING PROTECTION OF DISTRIBUTION TRANSFORMERS, L. G. Smith, Consolidated Gas, Lt. and Pwr. Co. Scheduled for Jan. 1936 issue

LIGHTNING PROTECTION OF DISTRIBUTION TRANSFORMERS, J. M. Flanigen, Georgia Power Co. Dec. issue, p. 1400–5

LIGHTNING INVESTIGATIONS IN CHICAGO, Herman Halperin and E. H. Grosser, Commonwealth Edison Co. Scheduled for Jan. 1936 issue

DISCHARGE CURRENTS IN LIGHTNING ARRESTERS, K. B. McEachron and W. A. McMorris, General Electric Co. Dec. issue, p. 1395–9

LIGHTNING ARRESTER ECONOMICS, Philip Sporn and I. W. Gross, American Gas & Electric Co. Scheduled for Jan. 1936 issue

2:00 p.m.—Conference on Electric Welding

DEMONSTRATION—APPLICATION OF HIGH-SPEED PHOTOGRAPHY TO THE STUDY OF WELD PHENOMENA, H. A. Winne, General Electric Co.

Great Lakes District Holds Fifth District Meeting at Purdue University

PURDUE UNIVERSITY, Lafayette, Ind., played host to some 400 members, students, and guests who attended the fifth general meeting of the Great Lakes District, October 24–25, 1935. Traditional Hoosier hospitality was extended by officials and faculty of the university, convenient and comfortable facilities for the technical and other sessions were provided, and generous arrangements made for the entertainment of those in attendance. Each of the 9 Sections in District 5 were well represented, as also were the 16 Student Branches in the District, special emphasis being placed upon the participation of Student groups in the technical sessions and other activities.

Opening Meeting

With Vice President G. G. Post officiating, the opening meeting started promptly on scheduled time at 9:30 Thursday morning, October 24, in the main lecture hall of the electrical engineering building, with an initial attendance in excess of 200. In response to Vice President Post's introduction, A. A. Potter, dean of the schools of engineering of Purdue University, and past-president (1933) of The American Society of Mechanical Engineers, delivered an address of welcome in which he heartily endorsed the idea of holding meetings such as this on University campuses, and stressed the growing importance in modern life of engineering education, outlining some of the leading trends in the development of curricula and teaching methods.

President Meyer in responding to Dean Potter's welcoming remarks, paid tribute to all who had participated in arranging the District meeting. He also took advantage of the opportunity to remind his audience that the institute is a wholly democratic organization of individual members and to emphasize the many opportunities offered for individual participation, pointing out that the return "dividend" to the individual depended quite entirely upon the degree to which the individual participated in Institute affairs.

Technical Sessions

Immediately following the opening meeting, the first of the technical sessions was held. As indicated in the detailed schedule published in the September 1935 issue of Electrical Engineering, pages 1005–7, the 2-day program provided 4 general technical sessions. Presiding officers for the several sessions were: for the general applications session, Vice President G. G. Post, Milwaukee, Wis., and Dr. C. F. Harding, Purdue University; for the session on electron tube theory and practice, Chairman C. A. Cora of the Central Indiana Section, Indianapolis, and Dr. C. B. Aiken of Purdue University; for the Student technical session, Student Counselor E. B. Kurtz of the University of Iowa, Iowa City, and Student Counselor A. N. Topping of Purdue University; and for the high potential measurements session, District Secretary A. G. Dewars of Minneapolis, Minn., Past Chairman O. Kiltie of the Fort Wayne, Ind., Section, and Prof. D. D. Ewing, of Purdue University.

Of the 4 general technical sessions mentioned above, 3 accommodated the presentation and discussion of: 14 formal technical pagers, 1 unpublished technical paper, and 2 special addresses; one session was devoted to the presentation and discussion of Student papers, 15 of which were scheduled. With but minor variations, the technical program as carried out was in accord with the published schedule. As all 14 of the formal technical papers were published in Electrical Engineering prior to the meeting, and as most of the discussions thereon will be published in future issues, these technical papers will not be further commented on here.

Analysis of Registration at Meeting

Classification	Central Indiana Section	District No. 5*	Other Districts	Totals
	Location			
Members	44	89	15	148
Students	170	84		254
Men Guests	15	13	3	31
Women Guests	10	12	2	24
Totals	239	198	20	457

*Outside of Central Indiana Section

Special Addresses

Two addresses of a special nature were presented during the technical sessions: one, "Dare We Become Efficient?" given by J. W. Esterline, president of the Esterline Angus Company of Indianapolis; the other, "Recent Electrical Developments in the Steel Industry," by Ralph H. Wright of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Mr. Esterline described the development and operation of the unique program of employee relations in vogue at the Esterline Angus plant, and reviewed some of the results of several years of operation with that program. He stated that the program was based upon a definite effort to bring about a fully co-operative working relationship not only between employees and management, but also between departmental groups. He described this plan as being in effect the recognition of each management, design, manufacturing and other working units as a separate, but of course interrelated working unit, each in effect taking a contract to carry on its specialized work, and assuming full responsibility for delivery of goods or services as the case may be. Increased profits resulting from this co-operative-competitive effort are divided equitably between employer and employee with results enthusiastically described by Mr. Esterline as being highly satisfactory to all parties concerned.

As typifying the many important advances made in steel producing equipment Mr. Wright gave a comparison of old and new methods of rolling sheet and tin plate. He pointed out that in the older and common processes the metal is reduced to the desired finished thickness by a slow and laborious hot rolling process involving the passage of small bars of steel back and forth through rolls operating at about 300 feet per minute. In contrast to this, some of the

Taken during the recent meeting of the Institute's Great Lakes District and Student Branch convention held at Purdue University, West Lafayette, Ind., Oct. 24–25, 1935, the photograph reproduced above shows some of those responsible for the success of this meeting

Left to right (both rows) are: Dr. A. A. Potter, dean of engineering schools, Purdue University; National Secretary H. H. Henline; Vice President G. G. Post, chairman of the general committee for this meeting; Dr. C. F. Harding, chairman of the papers committee, member of the general committee, and head of the department of electrical engineering at Purdue; President E. B. Meyer; D. T. Canfield, chairman of the entertainment committee and member of the papers committee; C. A. Cora, chairman of the Central Indiana Section, and member of the general committee and papers committee for this meeting; J. W. Esterline, who presented a special address on the subject "Dare We Become Efficient?" and D. L. Curtner, chairman of the attendance and publicity committee

most recently accepted methods permit the use of heated slabs from 3 to 6 inches thick and weighing several tons which pass first in a continuous process through a preliminary rolling at up to 2,000 feet per minute, and subsequently through cold rolling finishing processes operating on a continuous basis at speeds ranging from 500 to 1,200 feet per minute.

A scene in the lecture hall of the electrical engineering building at Purdue University, where the technical sessions of the recent Great Lakes District meeting were held. One of the student sessions is shown

Student Sessions

The Student technical session held Friday morning, October 25, occupied a position of importance on the program paralleling that of the other 3 general technical sessions. Attendance at the Student sessions topped 300, and keen interest was shown in the entire program which was followed through essentially as printed in advance in Electrical Engineering.

Following a Student luncheon meeting Friday noon, which turned out to be so popular that it developed into a general luncheon affair, the regular District conference on Student activities occupied the time of Student Branch chairmen and Branch counselors for the remainder of the afternoon.

Each Branch representative reported briefly concerning his Branch's activities for the past year, and outlined plans now under way for the current year, in most cases guided very constructively by accumulative local experience. Thus there was an effective interchange of experiences and ideas which repeatedly brought forth questions and precipitated spontaneous discussion on questions of more than average interest in connection with the pursuit of Branch affairs. To an observer interested in Institute work, and recognizing the strategic importance of Student Branch work, the general tone of the discussion was inspiring indeed. Most Branches in the District showed conclusively that they were keenly alive and were pursuing Branch organization aggressively, in many cases reporting the actual enrollment of all or of very high percentages of upper class electrical engineering students. Many Branches had segregated their social and technical programs.

Branch counselors present included: S. S. Attwood, University of Michigan; C. Boesewetter (alternate), Milwaukee School of Engineering; E. H. Freeman, Armour Institute of Technology; F. W. Kane, Marquette University; C. C. Knipmeyer, Rose Polytechnic Institute; J. H. Kuhlman, University of Minnesota; E. B. Kurtz, University of Iowa; B. K. Osborn, Michigan State College; F. A. Rogers, Lewis Institute; G. W. Swenson, Michigan College of Mining and Technology; A. N. Topping, Purdue University; G. F. Tracy, University of Wisconsin; H. O. Warner, University of Detroit; K. R. Weigand (alternate), University of Notre Dame; and Benn S. Willis, Iowa State College.

Student Branch chairmen present were: Wendell N. Becker, University of Iowa; Robert Berresford, Iowa State College; W. A. Brastad, University of Minnesota; C. Louis Del Gaizo, University of Notre Dame; Leonard B. Gezon, Michigan State College; Harry Holubow, Lewis Institute; R. B. Immel, Purdue University; Martin Long, Rose Polytechnic Institute; R. L. Oetting, University of Wisconsin; J. D. Scarbrough, Michigan College of Mining and Technology; Ray J. Schmitz, Jr., Marquette University; Curtis G. Talbot, University of Illinois; and Kenneth N. Wilkins, Milwaukee School of Engineering.

Thus, 13 out of the 16 Student Branches in the District were represented by their Branch chairmen, and, including 2 alternates, 15 were represented also by their Student conselors. Other members of the committee present were: District Vice President G. G. Post and District Secretary A. G. Dewars. Others present included: President E. B. Meyer, National Secretary H. H. Henline, Editor G. Ross Henninger, and D. C. Jackson, Jr., of Lewis Institute, Chicago.

Future AIEE Meetings

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 6–8, 1936

Summer Convention,
Huntington Hotel, Pasadena, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Pittsburgh, Pa., part of week of Oct. 12, 1936

Doctor Harding, officiating as toastmaster at the Student luncheon meeting, "summarized" the results of the District meeting as follows:

"Meetings such as this are stepping stones toward (1) better recognition of the electrical engineering profession by the public; (2) extension of geographic activities of the Institute in a manner that constitutes effective decentralization, (3) increasing Institute membership particularly among recent graduates, (4) broadening the technical, economic, and administrative scope of technical papers acceptable for publication, and (5) provision for earlier and less expensive transition and status from Enrolled Student to full membership."

Entertainment and Special Program

Entertainment features of a social nature provided by the local committee included: a dinner tendered Wednesday evening, in advance of the meeting, by Purdue University to the Section, District, and national officers present; the regular District dinner affair held Thursday evening in the ballroom of Purdue Memorial Union Building, and followed by a demonstration rehearsal in the stadium of Purdue's famous electrically illuminated band; and the general luncheon meeting that grew out of the Student luncheon Friday noon. Each of these groups was addressed by President Elliott, Dean Potter, and Doctor Harding of Purdue University, and by Institute President E. B. Meyer. Excellent musical entertainment was provided Thursday evening and Friday noon by Purdue University students.

Entertainment features of a technical nature included a television demonstration, a demonstration of the impulse "lightning" generator in the high voltage laboratory, demonstration of the university's radio station in operation, and visits to and special exhibits in the several engineering laboratories. In addition, inspection trips were arranged to the meter manufacturing plant of the Duncan Electric Manufacturing and to other points of interest according to visitors' choices.

District Executive Committee Meeting

Among the items of business transacted at the luncheon meeting of the executive committee of the Great Lakes District held on October 24, K. A. Auty, Commonwealth Edison Company, Chicago, Ill., was re-elected to the office of treasurer of the District. F. H. Lane, Byllesby Engineering and Management Corporation, Chicago, was elected a member of the Institute's national nominating committee, representing the Great Lakes District. Dr. C. F. Harding, head of the school of electrical engineering at Purdue University, was nominated unanimously as a candidate for the office of vice president of the Institute from the Great Lakes District, for the 2-year term beginning August 1, 1936.

The following members of the executive committee were elected to serve with the vice president, District chairman, and chairman of the District committee on Student activities, as members of the co-ordinating committee for the coming year:

Prof. J. F. H. Douglas	Milwaukee Section
Prof. S. S. Attwood	Detroit-Ann Arbor Section
Prof. F. H. Rogers	Chicago Section
H. P. Seelye	Detroit-Ann Arbor Section

Vice President Post appointed Professor Douglas as chairman of a special committee to determine the desires of the Sections

within the District, as to possible changes in the areas allocated to them. The Milwaukee Section's invitation to the Institute to hold its 1937 summer convention at Milwaukee was endorsed.

Past-President Johnson Memorialized

A resolution was passed by the Great Lakes District executive meeting at its October 24 meeting, commemorating the recent death of Junior Past President J. Allen Johnson. This resolution in memory of J. Allen Johnson, supplementing that passed by the Institute's board of directors on October 22, 1935 (see Electrical Engineering for November 1935, page 1274 for this resolution, and pages 1281–2 for an obituary item), is as follows:

Whereas: J. Allen Johnson was called from our midst by death on October 4, 1935; and

Whereas: Mr. Johnson was not only an engineer distinguished for his accomplishments but was also our friend and an indefatigable worker toward the general advancement of his, and our, profession, and

Whereas: Mr. Johnson during the 28 years of his membership had served the Institute capably and willingly in both local and national offices, including the presidency which he filled last year; therefore be it

Resolved: That the members of the Great Lakes District (No. 5) American Institute of Electrical Engineers, in convention assembled, hereby express their sense of great loss to the Institute in Mr. Johnson's passing and extend to the members of his family deep sympathy in their grievous loss, and be it further

Resolved: That copies of this resolution be sent to the Institute and the family.

Among other items at the meeting of the District executive committee, reports of past activities were presented by the delegates, and plans for coming meetings were outlined.

Standards on Letter Symbols and Abbreviations

Preparation of a new dictionary of letter symbols and abbreviations to be used by engineers and scientists is a task to be undertaken by a committee of the American Standards Association. The committee on symbols and abbreviations which has been at work for many years and which has already published several standards, has recently been divided into 2 parts, one covering the letter symbols and abbreviations, and the second covering the graphical symbols. The committee working on letter symbols and abbreviations, which is now beginning its work, has 12 subcommittees covering such broad subjects as mathematics, physics and mechanics, structural analysis, hydraulics, heat and thermodynamics, photometry and illumination, aeronautics, electric and magnetic quantities, radio, astronomy and surveying, geodesy, and scientific and engineering terms.

Any group which has its own standards for symbols, or has comments on standards which have already been approved, or has suggestions for useful new letter symbols and abbreviations, should communicate with Dr. J. Franklin Meyer (A'08, M'13), National Bureau of Standards, Washington, D. C., chairman of the committee.

A.I.E.E. Directors Meet at Institute Headquarters

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on October 22, 1935.

There were present: *President*—E. B. Meyer, Newark, N. J. *Past-President*—J. B. Whitehead, Baltimore, Md. *Vice Presidents*—C. V. Christie, Montreal, Que., Can.; W. H. Harrison, Philadelphia, Pa.; N. B. Hinson, Los Angles, Calif.; F. J. Meyer, Oklahoma City, Okla.; and R. H. Tapscott, New York, N. Y. *Directors*—F. Malcom Farmer, New York, N. Y.; N. E. Funk, Philadelphia, Pa.; H. B. Gear, Chicago, Ill.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; W. B. Kouwenhoven, Baltimore, Md.; Everett S. Lee, Schenectady, N. Y.; A. H. Lovell, Ann Arbor, Mich.; L. W. W. Morrow, New York, N. Y.; G. C. Shaad, Lawrence, Kans.; A. C. Stevens, Schenectady, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*— H. H. Henline, New York, N. Y.

The minutes of the board of directors' meeting of August 6, 1935, were approved.

By rising vote, a resolution was adopted in memory of Past-President J. Allen Johnson, who died on October 4. (The resolution was published in the November issue, page 1274, supplemented by a comprehensive biographical sketch on pages 1281–2.)

Reports were presented and approved of meetings of the board of examiners held September 25 and October 16. Upon the recommendation of the board of examiners, the following actions were taken: 3 applicants were transferred to the grade of Fellow; 14 applicants were elected to the grade of Member, and 67 applicants were elected to the grade of Associate as of November 1, 1935; 27 applicants were transferred to the grade of Member; 445 Students were enrolled.

The finance committee reported monthly disbursements amounting to $15,178.69 in September and $26,839.33 in October. Report approved.

A budget for the appropriation year beginning October 1, 1935, was submitted by the finance committee and adopted.

Upon the recommendation of the executive committee of the Middle Eastern District, approval was given to changing the location of the 1936 District meeting from Akron, Ohio, to Pittsburgh, Pa., to be held in connection with meetings of other engineering societies during the week of October 12.

The board adopted amendments approved at the August board meeting to Sections 22 and 23 of the by-laws, to bring them into conformity with the recently amended sections of the constitution. The amended by-laws read as follows:

Sec. 22. During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each Geographical District that by December fifteenth of that year the executive committee of each District must select a member of that District to serve as a member of the national nominating committee and shall, by December fifteenth, notify the secretary of the national nominating committee of the name of the member selected.

During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each Geographical District in which there is or will be during the year a vacancy in the office of vice president, that by December fifteenth of that year a nomination for a vice president from that District, made by the District executive committee, must be in the hands of the secretary of the national nominating committee.

Between October first and December fifteenth of each year, the board of directors shall choose 5 of its members to serve on the national nominating committee and shall notify the secretary of that committee of the names so selected, and shall also notify the 5 members selected.

The secretary of the national nominating committee shall give the 15 members so selected not less than 10 days' notice of the first meeting of the committee, which shall be held not later than January 31. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the national nominating committee must be received by the secretary of the committee by December 15. The nominations as made by the national nominating committee shall be published in the March issue of Electrical Engineering (Journal of A.I.E.E.), or otherwise mailed to the Institute membership not later than the first week in March.

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the secretary of the national nominating committee not later than March 25 of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with Article VI of the constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

The following members of the board were selected to serve on the national nominating committee: F. Malcolm Farmer, W. H. Harrison, W. B. Kouwenhoven, Everett S. Lee, and A. C. Stevens.

A. M. MacCutcheon was reappointed a representative of the Institute on the standards council of the American Standards Association for the 3 year term beginning January 1, 1936, and H. S. Osborne and E. B. Paxton were reappointed alternates for the year 1936.

W. S. Barstow was reappointed an Institute representative on the library board of United Engineering Trustees, Inc., for the 4 year term beginning in October 1935.

A. W. Berresford was appointed to fill the unexpired term, ending in October 1938, of J. Allen Johnson, deceased, on the John Fritz Medal Board of Award.

H. L. Huber was appointed to represent the A.I.E.E. committee on communication, and R. N. Conwell, the committee on power transmission and distribution, upon the American Committee on Marking of Obstructions to Air Navigation.

Chairman Everett S. Lee of the membership committee reported on the state of the Institute membership and the activities of the membership committee, with particular emphasis upon the effective work of the Section membership committees.

Upon the recommendation of the standards committee, the board authorized the submission of a revised report on standards for relays to the American Standards Association, with the endorsement of the Institute, as material for an American standard.

The board accepted, with appreciation, an offer of Past-President Ralph D. Mershon to donate a third golf trophy, to remain permanently in possession of the Institute, and

to take the place of the second golf trophy, which was won by L. R. Keiffer at the 1935 summer convention, at Ithaca, N. Y.

Approval was given to a proposal that the Engineers' Council for Professional Development become incorporated.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

President Meyer to Serve M.I.T.

Upon invitation of Dr. Karl Taylor Compton (F'31), president of Massachusetts Institute of Technology, President E. B. Meyer of the A.I.E.E. has been appointed to serve as a member of the M.I.T. visiting committee of the department of electrical engineering for the academic year beginning October 1935.

It is the custom of M.I.T. to invite distinguished members of the fields with which its work is concerned to serve with members of its corporation and representatives from its alumni body upon committees which "consider critically and constructively the problems and policies of the various departments and which report their findings and recommendations to the corporation."

Other prominent Institute members serving M.I.T. on this special committee include Dr. Frank B. Jewett (A'03, M'10, F'12, past president), New York, N. Y.; Thomas Spooner (A'12, M'23, F'29), East Pittsburgh, Pa.; and Don L. Galusha (A'05, M'13, F'19), Philadelphia, Pa.

A.I.M.E. Nominates Officers for 1936. Nominations of officers to serve the American Institute of Mining and Metallurgical Engineers for the year 1936, have been made. J. M. Lovejoy, president of the Seaboard Oil Company, has been nominated to serve as president. For 2 vacancies as vice president and director, R. C. Allen and Henry Krumb were nominated. New directors nominated include: S. G. Blaylock, James Douglas, Medalist in 1928 and vice president and general manager of the Consolidated Mining and Smelting Company of Canada; J. L. Christie, metallurgist for the Bridgeport Brass Company; E. T. Conner, Scranton, Pa.; W. B. Heroy, chief geologist, Consolidated Oil Corporation; and F. L. Sizer, San Francisco, Calif. The last 3 were nominated for re-election.

Air Conditioning Standards Adopted. At the October, 1935 meeting of the Air Conditioning Manufacturers' Association held in Chicago, Ill., standards for rating and testing air conditioning equipment were adopted. These standards are the result of many weeks of investigation and study by leading air conditioning engineers, representing not only the manufacturers but also the American Society of Refrigerating Engineers and the American Society of Heating and Ventilating Engineers, which are the leading technical societies in the air conditioning field. Much of the uncertainty which has confronted buyers of air conditioning equipment is said removed by this action of A.C.M.A.

John Fritz Medal Awarded W. F. Durand

At the annual meeting of the John Fritz Medal board of award, the Gold Medal for 1936 was awarded William Frederick Durand for notable achievement "as authority in hydrodynamic and aerodynamic science, and in its practical application; outstanding leader in research and in engineering education." This award was made unanimously by a board having for its members 16 past-presidents of the 4 American societies of civil, mining and metallurgical, mechanical, and electrical engineers.

Doctor Durand is professor emeritus of mechanical engineering, Stanford University, Calif. He was born May 5, 1859, in Bethany, Conn., and graduated from the United States Naval Academy in 1880. He served in the Engineers Corps of the Navy until 1887, and then became professor of mechanical engineering at what is now Michigan State College, Lansing. He went to Cornell University in 1891, and remained there as professor of marine engineering until 1904, when he went to Stanford University to become professor of mechanical engineering.

Early in life Doctor Durand became interested and active in scientific and engineering research. In particular, he devoted his attention to problems of ship propulsion, hydraulics of pipes, and later to aeronautics, being one of the first to engage in scientific research in aeronautics. He has invented precision measuring instruments.

In 1916, he became chairman of the National Advisory Committee for Aeronautics, authorized by Congress, which committee he had assisted in organizing in 1914. During the war, he was in Paris as a representative of the United States government on technical commissions. In 1925, he was appointed by President Coolidge a member and secretary of the aircraft board, and in 1935 he was appointed by President Roosevelt chairman of a committee of review of airship design and construction for the U.S. Navy. He has frequently served as a consultant to the U.S. Bureau of Reclamation.

Doctor Durand was a trustee of the Guggenheim fund for the promotion of aeronautics throughout the life of that organization. In May 1935, Doctor Durand was awarded the Daniel Guggenheim medal for aeronautical achievement. He received the degree of doctor of philospho from Lafayette College in 1888, and was awarded the honorary degree of doctor of laws by the University of California in 1927. Doctor Durand is a Gold Medalist of the American Society of Naval Engineers, and a past-president of The American Society of Mechanical Engineers. He is general editor for a comprehensive work on aerodynamic theory, now being printed in 6 volumes.

Communication Museum for Canada

While there are rare and valuable collections of telegraph, telephone, and radio historical apparatus in the Smithsonian Institute, Washington, D. C.; Franklin Institute, Philadelphia, Pa.; Science Museum, New York, N. Y.; and the new museum in Chicago, Ill., it was found that no historical museum had been established in Canada. To remedy this situation Donald McNicol (A'05, F'18), past-president of the Institute of Radio Engineers, gathered and procured through purchase several private collections in the United States and Canada. These he has donated to Canadian communication engineers in the form of a museum which is housed in Ottawa. At present the telegraph and telephone items are housed in the Dominion archives department, and the radio items in the National Research Building, but shortly the collections are to be consolidated in the latter building.

The museum consists of more than 100 rare and valuable items.

In arranging for proper housing for the museum Mr. McNicol had the co-operation of Col. W. Arthur Steel, Canadian broadcast commissioner, and John McMillan, late general manager of the Canadian Pacific Railway Telegraphs.

Membership—

Mr. Institute Member:

Next month the membership committee will invite into Associate membership those Students who were graduated last June. There are 1,304 of these young men. Personal letters from Institute headquarters and personal contacts from the Section membership committees will bring the invitation.

The membership committee asks that where you may know any of these young men, you do what you can to acquaint them further of Institute activities.

Everett S. Lee

Chairman National Membership Committee

District and National Prizes Available for 1935 Technical Papers

ALL who have presented technical papers before the Institute during the calendar year 1935 are eligible under the A.I.E.E. paper prize regulations for competitive consideration for one or more of the established prizes. Papers are eligible for submission to the prize committees regardless of whether presented before a Branch meeting, a Section meeting, a District meeting, or a national convention, the several classes providing for equitable competition.

Papers Must Be Submitted

Although all 1935 papers are *eligible* for consideration, every paper for which prize consideration is desired, must be *submitted* specifically for that purpose, except as noted below: through the District secretary for consideration for the District prizes, and through the national secretary's office for consideration for the national prizes. There is no provision for automatic consideration of papers, with the exception that those approved by the technical program committee and presented at national conventions or District meetings, will be considered by the national prize committee for the national "best paper" and "initial paper" prizes without being formally offered for competition.

Both District and national prize awards are made each spring for papers presented during the preceding calendar year, provided they are submitted for prize consideration not later than February 15. Prize rules governing 1935 papers were published in full on page 342 of the March 1935 issue of Electrical Engineering. However, inasmuch as these rules contained many changes, they are republished here in full for the convenience of authors, as well as District Section, and Branch officers, and others interested.

National Prizes

The following national prizes may be awarded each year at the discretion of the committee on award of Institute prizes:

1. Prize for best paper in: (1) engineering practice; (2) theory and research; and (3) public relations and education.
2. Prize for initial paper.
3. Prize for Branch paper.

The national prize for best paper in each of the 3 classes, namely, engineering practice, theory and research, and public relations and education, may be awarded for the best original paper presented at any national, District, or Section meeting of the Institute, provided the author, or at least one of co-authors, is a member of the Institute.

The national prize for initial paper may be awarded for the most worthy paper presented at any national, District, Section, or Branch meeting of the Institute, provided the author or authors have never previously presented a paper which has been accepted by the technical program committee, and the author, or at least one of co-authors, is a member of the Institute or is a graduate student enrolled as a Student of the Institute.

The national prize for Branch paper may be awarded for the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, provided the author or authors are Enrolled Students of the Institute.

Only papers presented during the calendar year shall be considered for any of the prizes, except those for the best paper prize in the class of public relations and education. In this class, all papers presented subsequent to those considered at the time of the last previous award in this field will receive consideration. All papers approved by the technical program committee which were presented at the national conventions or District meetings will be considered for the best paper prizes and initial paper prize without being formally offered for competition. All other papers which were presented at Section, Branch, or Student meetings must be submitted in triplicate with written communications to the national secretary on or before February 15 of the following year, stating when and where the papers were presented. This may be done by authors, by officers of the Institute, or by executive committees of Sections or geographical Districts.

Each national prize shall consist of a certificate of award issued by the Institute and $100 (see note below) in cash. When papers are written jointly, the cash awards shall be divided and a certificate shall be issued to each author. The board of directors may, at its discretion, omit the cash awards for any of the prizes.

Committee on Award of Institute Prizes. This committee shall consist of the chairman of the technical program committee, acting as chairman; the chairmen of the publication committee, the committee on research, the technical program committee of the previous year, and the chairmen of such other committees as the board of directors may designate. This committee shall award at its discretion all the national prizes. It may award a single paper more than one of the prizes available and it may make honorable mention of papers which do not receive prize awards. All the national prizes for a given calendar year shall be awarded prior to May 1 of the succeeding year. They shall be presented at the next summer convention of the Institute.

For the national best paper prizes the technical program committee shall indicate to the committee on award of Institute prizes the class under which each paper is to be considered for first prize.

Basis of Grading Papers. The technical committees shall assist the committee on award of Institute prizes by grading papers at the time they are initially reviewed for acceptance. The valuations which shall govern the grading of papers for purposes of making awards shall be as follows:

Analysis of Subject....................10 per cent

The paper shall present a clear outline of the situation out of which arises the need for the preparation of a paper on the particular subject, explaining the point of view assumed in the presentation.

Logical Presentation..................10 per cent

The presentation should include an analysis of the difficulties encountered, the methods of attack and the solution of the problem.

Originality..........................10 per cent

Credit should be given to the paper which brings to its subject matter a fresh point of view, a healthy open-mindedness or a discarding of some outworn traditions.

Unity...............................10 per cent

While brevity and conciseness are important they should not be attained at the sacrifice of unity and completeness of presentation.

Value in Its Field...................30 per cent

The value of the paper as a contribution to the literature in its own field should receive particular consideration.

Value to Electrical Engineering........30 per cent

The paper should be considered from the standpoint of the quality of its contribution to the advancement of electrical engineering and its value to civilization.

Publication. Papers awarded prizes shall be published in full or in abstract, in Electrical Engineering, in the Transactions, or in pamphlet form:

District Prizes

The following District prizes may be awarded each year in each geographical District of the Institute:

1. Prize for best paper.
2. Prize for initial paper.
3. Prize for Branch paper.

The District prize for best paper may be awarded for the best paper presented at a national, District, or Section meeting, provided the author, or at least one of co-authors, is a member of the Institute.

The District prize for initial paper may be awarded for the most worthy paper presented at a national, District, Section, or Branch meeting, provided the author or authors have never previously presented a paper before a national, District, Section, or Branch meeting of the Institute, and the author, or at least one of co-authors, is a member of the Institute or is a graduate student enrolled as a Student of the Institute.

The District prize for Branch paper may be awarded for the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, provided the author or authors are Enrolled Students of the Institute.

Each District prize may be awarded only to an author who, or to co-authors of whom at least one, is located within the District, and for a paper presented at a meeting held within, or under the auspices of the District.

Only papers presented during the calendar year shall be considered. They must be

Note—By action of the board of directors, all cash prizes for papers presented during the calendar year 1935, with the exception of the prize for Branch paper in each District, are to be omitted. Certificates, however, will be awarded to all winners as usual.

submitted in duplicate by the authors or by the officers of the Branch, Section, or District concerned to the District secretary, on or before February 15 of the following year.

Each District prize shall consist of a certificate of award issued by the officers of the geographical District and $25 (see note below) in cash. When papers are written jointly, the cash awards shall be divided and a certificate shall be issued to each author. The board of directors may, at its discretion, omit the cash awards for any of the prizes.

Committees on Awards. All the District prizes for a given calendar year shall be awarded prior to May 1 of the succeeding year by the District executive committee or by a committee appointed by the District executive committee and authorized to make such awards.

Basis of Grading Papers. The valuations which shall govern the grading of papers for purposes of making awards shall be the same as those for the national prizes but the papers will not be graded by the technical committees.

Copies of a pamphlet entitled "National and District Prizes" may be secured, without charge, upon application to Institute headquarters. The information given in this pamphlet is identical with that presented above. These rules were originally adopted by the Institute's board of directors June 23, 1927; they were revised December 7, 1928, January 27, 1932, and January 21, 1935. The rules given above include the latest revisions.

Note—By action of the board of directors all cash prizes for papers presented during the calendar year 1935, with the exception of the prize for Branch paper in each District, are to be omitted. Certificates, however, will be awarded to all winners as usual.

New Wood Handbook Considers Utility Needs

A handbook specifically adapted to the principal classes of wood use was published recently by the U.S. Forest Products Laboratory, Madison, Wis., headquarters of wood research for the federal Forest Service. This handbook is reported to be the first publication of its kind to bring the requirements of public utilities and railways to definite focus with the properties and characteristics of American wood species as a whole in their treated and untreated condition.

The selection and use of lumber and timber for general construction are dealt with in respect to grade, defects, strength characteristics, decay resistance, and ability to hold paint, and the effectiveness of various types of paints and finishes is given special attention. Of direct bearing on problems of timbering are the condensed data on mechanical properties of wood and the facts recently established in regard to growth ring placement, fatigue effects, seasoning, and shear relations. The chapter on timber fastenings includes the latest information on nails, screws, bolts, spikes, and the new plate and ring connectors which have greatly enlarged the engineering possibilities of wood in transmission towers, radio masts, bridges, and other heavy construction.

The characteristics of standard wood preservatives are explained and the merits of the various processes set forth in relation to the kind of wood and the type of use. The hazards of decay and of attack by insects, marine borers, birds, and rodent animals are dealt with and corrective measures shown.

Public utility and railway requirements in poles, ties, and piling are taken up in a special section of the handbook. Piling data are presented, and comprehensive information on crossties is given.

Replacing reams of scattered pamphlets, magazine articles, and miscellaneous publications, this handbook is considered to bring within its 306 pages the essential data on wood as a material of construction and use. The new "Wood Handbook" is listed as U.S. Department of Agriculture unnumbered publication and can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 25 cents per copy, cash or money order.

Washington Award Commission Elects Chairman. For the year 1935–36, the Washington Award Commission has elected Frank D. Chase, member and past president of the Western Society of Engineers, chairman of the commission. This commission annually presents the Washington award, established in 1916 by Past-President Alvord of the Western Society of Engineers "to an engineer whose work in some special instance, or whose services in general, have been noteworthy for their merit in promoting the public good." The Washington Award Commission is composed of: C. A. Morse, F. H. Lane (M'23), D. J. Brumley, Frank D. Chase, M. M. Leighton, L. R. Howson, C. H. MacDowell, W. W. DeBerard, and L. R. Mapes (M'29), all representing the Western Society of Engineers; and the following representatives of the 4 founder societies: E. J. Mehren and Samuel A. Greeley (A.S.C.E.); J. R. Van Pelt and Gustav Egloff (A.I.M.E.); C. B. Nolte and O. A. Leutwiler (A.S.M.E.); and William B. Jackson (A'97, F'13, and past vice-president) and L. A. Ferguson (A'01, F'12, and past-president) (A.I.E.E.).

At the Recent Meeting of the Great Lakes District at Purdue University

ABOUT 170 out of the total of 457 registered for the Institute's Great Lakes District meeting held at Purdue University, West Lafayette, Ind., Oct. 24–25, 1935, are shown here. This group contains many Students, who were given special attention at the meeting, both to their benefit and that of many of the older members present. In the upper central background may be discerned one of the towers of Purdue's high voltage experimental transmission line. In the central foreground appear (left to right) Dr. C. F. Harding of Purdue, Vice President G. G. Post of Milwaukee, President E. B. Meyer, Vice President N. B. Hinson of Los Angeles, National Secretary H. H. Henline, and Director P. B. Juhnke of Chicago. A report of the meeting is given on pages 1410–12 of this issue.

N.R.C. Electrical Insulation Committee Holds Eighth Annual Meeting at Pittsfield

THE eighth annual meeting and conference of the committee on electrical insulation, National Research Council held October 17 and 18, 1935, at Pittsfield, Mass., as guests of the General Electric Company, was unusually successful and interesting. It embraced 3 technical sessions in which 24 papers and progress reports of research were discussed, an evening lecture by Dr. Irving Langmuir, and high voltage demonstrations and inspections in the research laboratories and plants of the General Electric Company. Seventy-six members were registered and a number of local visitors participated. The following news report was prepared by A.I.E.E. Past-President J. B. Whitehead, long-time chairman of the N.R.C. insulation committee.

The normal functions of the committee are the stimulation and co-ordination of research and the gathering, discussion, and publication of its results. The work in these several directions is unified at the annual meeting and conference. The papers presented are largely in the form of progress reports, and finished manuscripts are neither exacted nor expected, nor is there any formal record of the discussions. Most of the papers presented ultimately find publication in current scientific and technical journals. It is believed that the continued success and interest in the work of the committee is largely due to these informal features of its operation. Subcommittees on chemistry and physics are active in following current work in these fields. A subcommittee on monographs has already directed the publication, under the auspices of the committee, of 4 volumes of moderate size by competent authors, on selected subjects in the field of dielectrics and insulation. Several other volumes in the same series are in the process of preparation.

Papers on Basic Chemistry and Physics

A conspicuous aspect of the technical program of the recent meeting was the large number of papers on the basic chemistry and physics of dielectrics. Those in the chemical field indicated a substantial spread in the attack of the problem of instability in high voltage insulation. With the realization of the obscurity of this problem, researches in recent years have been pushed more and more deeply into the study of molecular structure, particularly in its chemical aspect. There were 6 progress reports in this field. They dealt particularly with refinements and extensions in the chemical testing of oils, in the separation of oils into more nearly pure components, with the oxidation of insulating oils, particularly as regards those aspects of oxidation which may be correlated with electrical behavior and the like. The extent of this problem in the important field of insulating oils was indicated in the statement that present methods of refinement permit the segregation of the hydrocarbons in petroleum oils only into certain broad groups such as gasoline, kerosene, lubricants, and the like. Hardly 5 per cent of a crude oil may be recognized as definite hydrocarbons and these are all in the gasoline group. No single definite hydrocarbon has yet been isolated from the viscous fractions of petroleum within which the insulating oils are commonly found. Attention was also called to the fact that no correlation is as yet possible between the dielectric strength of an oil and its chemical or physical structure. Much the same thing may be said as to the several other important electrical properties. It is commonly believed that oxidation is one of the most important causes of deterioration in high voltage insulation. A number of experimental studies of various aspects of the oxidation process as related to deterioration are under way. A paper of special interest reported results from the effects of admixture of anhydrous oxidation products of pure oils as related to their conductivity and to the behavior of paper impregnated with the original oils and as modified. The results were quite definite in segregating certain classes of oxidation product as having little effect on conductivity and loss and others as being markedly harmful. Another striking report was a review of the experimental processes back of the development of "pyranol," a recently developed noninflammable insulating liquid. This report presents a fine example of the advances possible through carefully considered experimental research.

In the field of physics further results were reported of X ray studies on rubber as bearing on changes under electric stress. Further data were presented on the influence of pressure on the breakdown strength of oils. Several papers were devoted to existing theories of dielectric absorption and conduction, with special reference to underlying causes in the light of new experimental data. Simplified methods of computation in practical cases for the avoidance of the inherent complexities of the phenomena themselves were also proposed. Of special interest in this direction was a paper on the distribution of the wide range of value of the relaxation time often encountered in solid dielectrics, the study being an extension of the Maxwell-Wagner analysis with a method for evacuating the Wagner constants from typical experimental studies. A method for studying ionic mobilities in insulating oils was also reported with experiments indicating unexplained high values of such mobilities in liquids of relatively high viscosity.

Papers in Field of Application and Practice

Equally interesting were the papers in the field of application and practice. Several papers reported oscillographic and other studies on the electrical oscillations produced in systems of high voltage conductors by incipient spark discharge and ionization such as mark the beginnings of cable failures. The range of frequency of these oscillations was explored and as related to stress, temperature, pressure, and other factors. The predominance of such oscillations in the parallel connection of test samples was shown and methods proposed for suppressing such oscillations. An extensive series of aging tests through over-voltage and temperature cycles on 66 kv cable was reported with studies of the mechanism of failure. The results of these tests point away from the importance of initial power factor and loss measurements, as well as a radial distribution of the values of these quantities, as dominating factors in the life of cables. More important factors seem to be original care and thoroughness in impregnation. Ultimate failure in these tests was apparently due to a more or less widely distributed process of deterioration rather than to thermal failure arising in a local high conductivity or other imperfection.

A report on progress and research in the field of dielectrics and insulation during the foregoing year was presented by the chairman, Dr. J. B. Whitehead. This report appears in full beginning on page 1288 of this issue of ELECTRICAL ENGINEERING.

Dr. Langmuir, under the title "random thoughts on dielectrics," dealt with the atomic aspects of dielectric structure, particularly as regards the significance of electronic energy levels within the atom in their relation to the processes of ionization. The lecture was followed by an interesting and illuminating informal discussion.

A.S.T.M. Standards on Insulating Materials

The "Standards on Electrical Insulating Materials" recently published by the American Society for Testing Materials presents under a single cover A.S.T.M. standards that are in widespread use for testing and evaluating electrical insulating materials. The 1935 edition, 311 pages, gives 25 standardized methods of test and 10 specifications. The method of testing shellac has not been published heretofore. During 1935, revisions were made in a number of the test methods including those covering the following: varnishes, solid filling and treating compounds, molding powders, sheet and plate materials, laminated tubes and round rods, natural mica, and flexible varnished tubing.

Specifications which have been revised cover the following materials: friction tape, rubber insulating tape, and flexible varnished tubing.

The current report of committee *D*-9 outlines the extensive research and standardization work under way, gives a modified Baader saponification test for insulating oils and proposed requirements for rubber insulating blankets.

The following materials are also covered by specifications or tests given in the book: rubber gloves, rubber matting, electrical cotton yarns, silk and cotton tapes, pasted mica, and slate; also, black bias cut varnished tape; asbestos yarns, tape and roving; untreated paper; electrical porcelain; and insulating oils. Other tests which are included cover procedures for thickness

testing, impact, thermal conductivity, resistivity.

Copies, bound in heavy paper cover, can be obtained from A.S.T.M. headquarters, 260 S. Broad St., Philadelphia, at $1.75 per copy. Special prices are in effect on orders for 10 or more copies.

"The Handbook of Chemistry and Physics" (flexible fabrikoid, 4 by $6^1/_2$ inches, 1,951 pages, $6) newly revised, enlarged, and otherwise brought up to date, has just been published by the Chemical Rubber Publishing Company of Cleveland, Ohio. For some 22 years, this handbook has served those having need for accurate tables, formulas, and scientific data in a single convenient volume. The current issue is materially more complete than earlier issues. Material prepared for the 20th edition includes the following important features: physical constants of organic compounds, formula index of organic compounds, the pronunciation of chemical words, rules for naming organic compounds, prefix names of organic radicals, properties of the amino acids, X ray spectra, magneto-optic rotation, colorimetry, photometry, and a wealth of other information in tabular form including mathematical tables, properties and physical constants, general chemical tables, heat, hygrometry, sound, electricity, light, and miscellaneous quantities and units, all of which should be invaluable in the commercial, educational, or research laboratory.

Hughes Medal Awarded. The Hughes Medal has recently been awarded by the Royal Society (London, Eng.) to Dr. C. J. Davisson, research physicist of the Bell Telephone Laboratories, Inc., New York, N. Y., for his discovery, jointly with Dr. L. H. Germer, of electron diffraction. The award, established in 1900, has been conferred on such distinguished scientists as Dr. Alexander Graham Bell, Dr. O. W. Richardson, Dr. W. D. Coolidge, Dr. Irving Langmuir, and Mr. E. V. Appleton. Electron diffraction is what takes place when a stream of electrons is shot into a suitable crystal. The atoms, arranged in a regular pattern in the crystal, cause the electrons to emerge in a few sharply defined beams. Occurrence and disposition of the beams can only be explained by the hypothesis that electron streams behave in some respects like trains of wave such as those of light and X rays. Since it was well known that electrons are just as discrete particles as the pellets of lead from a shot gun, the idea that a stream of them could also be treated as a beam of light was a forward step which opened up wide vistas to the atomic physicist.

Radio Data Charts. A second edition of "Radio Data Charts" which contains many new charts added in accordance with modern developments has been issued by Iliffe and Sons Ltd., Dorset House, Stamford Street, London, and is priced at 4s 6d net, or 4s 10d postpaid. The nomographs enable results to be obtained quickly which otherwise require laborious calculation, and are intended to be useful in the design of coils, transformers, etc., and to give other essential data. Explanatory notes are included. R. T. Beatty is the author.

Institute Finances for 1935–36

THE board of directors and the finance committee of the Institute feel that no better opportunity is afforded to inform the membership regarding developments affecting the organization and activities of the Institute than the presentation of the budget of estimated income and expenditures for the appropriation year beginning October first, in conjunction with the report of actual revenue and expenses of the preceding year. While information regarding the finances of the Institute is regularly furnished to the membership in the annual report of the board of directors, it is not feasible on that occasion to furnish a statement of details which would explain the underlying reasons for increases or decreases in expenditures for various activities.

Accordingly, the following comments are given to explain the expenditures authorized in the new budget for those activities considered by the board of directors and finance committee to be of major interest to the greatest number of members, together with a table of expenses and income with comparative figures for the last appropriation year (see table I).

Publications

Electrical Engineering—Transactions. Under the unified publication policy in effect since January 1934, the budget provides for publication in the official monthly journal, Electrical Engineering, of approximately the same amount of technical papers and discussions as printed last year (1,380 pages) and for subsequent publication of identically the same material in the corresponding bound volume of Transactions, which latter publication is distributed to members and others who have duly authorized the subscription charge for such volume. Since the adoption of the budget, it has also been decided to incorporate in the December 1935 issue of Electrical Engineering, the annual reference index to papers and discussions published during the year, rather than to provide this index in separate pamphlet form for distribution only upon request.

Year Book. Last year's appropriation for the Institute Year Book provided funds only to meet the necessary expenses for maintaining the membership and mailing records. The budget for the present year contemplates the publication of a revised edition of the Institute Year Book early in 1936, on the basis of an edition of 4,000 copies, to be sent to members of the Institute upon receipt of request. An announcement will appear in the news columns of Electrical Engineering as soon as the 1936 edition is ready for distribution.

Institute Meetings

The expense for holding the annual winter convention in New York City in January has been provided for on about the same basis as last year; the appropriation for the summer convention at Pasadena, Calif., in June 1936 exceeds the cost of last year's convention by reason of the distant location of the meeting and the consequent increase in traveling expenses.

The appropriation for the Middle Eastern District meeting held last month in West Lafayette, Ind., as well as the North Eastern District meeting to be held in New Haven Conn., May 6–8, 1936, contemplates the same expenditures as paid for similar meetings in the past.

Institute Sections

After having received the co-operation of all Institute Sections during the past 4 years in the acceptance of a voluntary reduction in the annual appropriation, it is a pleasure to report that the budget provides this year for full payment of the financial support to Sections as specified in Section 48 of the by-laws; i. e., a flat appropriation for each Section of $175, plus an allowance of $1 for each active member located within the territory of the Section on August first.

Institute Branches

Reimbursement of routine expenditures incidental to the holding of meetings at Institute Branches is expected to involve about the same expenditures as last year; other items of expense chargeable to Branch activities have been provided for similarly. Under the paragraph captioned "traveling expenses" will be found an explanation of the allowances authorized for Branch representatives to the District conferences on student activities, and for the Counselor Delegates to the summer convention.

Administration

Almost $^3/_4$ of the appropriation for administrative expenses is required for salaries, this appropriation covering 41 per cent of the total salaries paid to 20 members of the headquarters staff, in addition to the full salary of the national secretary and the office manager. In this connection it is pertinent to mention that the Institute maintains the smallest staff per 1,000 members of any of the founder societies. At the recommendation of the finance committee, the board of directors voted to restore the balance of the headquarters staff salary reduction voted in June 1932 to the extent of approximately 3 per cent of the salaries paid.

Other items in this appropriation are provided for to the same extent as last year; expenditures for postage, printing, and mailing of general announcements to the membership, telephone and telegraph service, insurance, office equipment, miscellaneous supplies and services not chargeable to specific appropriations, etc.

Traveling Expenses

With the object of providing reimbursement of substantially all of the expense incurred for railroad fare, Pullman accommodations, and meals en route, the traveling allowance to District, Section, and Branch

Table I—Institute Income and Expenses for Year Ending September 30, 1935, and Budget for Year Ending September 30, 1936

	Actual Income and expenses year ending 9/30/35	Budget for year ending 9/30/36
Income		
Dues	$174,543.17	$175,500.00
Students' fees	9,156.00	9,000.00
Entrance fees	5,161.90	5,000.00
Transfer fees	1,065.00	1,000.00
Advertising	22,514.80	25,000.00
ELEC. ENGG.—non-member subscriptions	12,322.43	12,500.00
TRANS. subscriptions	6,411.15	6,500.00
Miscellaneous sales	6,269.23	5,750.00
Badge sales	1,332.50	1,250.00
Interest on securities	7,546.19	7,425.00
Excess of estimated expenses over est. income		1,132.26
Total	$246,322.37	$250,057,26
Expenses		
Publications		
Text matter	$ 64,638.65	$68,080.00
Advertising section	10,687,54	11,475.00
YEAR BOOK	2,340.14	6,300.00
Institute meetings	10,800.87	11,430.00
Institute Sections		
Appropriations	17,974.45	21,554.00
Trav. exp. convention delegates	2,705.30	7,200.00
Other expenses	4,995.88	5,600.00
Institute Branches		
Meeting expenses	728.32	1,000.00
Trav. exp. District Conferences on Student activities	2,803.30	5,250.00
Trav. exp. Counselor Delegates to convention	536.75	1,100.00
Other expenses	1,832.87	1,910.00
Administration		
Headquarters salaries	31,468.23	32,750.00
Postage	3,228.54	3,300.00
Stationery and printing	3,230.05	3,300.00
Office equipment	424.74	500.00
Trav. exp. nat'l secy	123.25	1,000.00
Telegraph and telephone, insurance, express, misc. supplies and services	2,491.21	2,350.00
Membership committee	7,315.43	7,125.00
Standards committee	5,394.61	6,775.00
American Standards Assn.	1,000.00	1,000.00
American Engg. Council	9,000.00	10,000.00
Engineering Societies Employment Service		
New York Office	3,201.39	3,400.00
Wash. D. C. rep.	333.32	
Traveling exp. general		
Board of directors	5,045.57	7,000.00
Geographical Dists.	1,100.60	2,250.00
Nat. nominating com.	1,300.67	650.00
President's appropriation	737.30	1,500.00
United Engg. Trustees		
Building assessment	5,153.31	5,882.28
Library assessment	8,586.39	8,759.60
Library equipment	468.75	2,111.38
Other committees and miscellaneous expenses	8,854.84	9,505.00
Total	$218,502.27	
Excess income, applied toward replacement of withdrawals from reserve capital fund, to meet operating deficits years 1930–32	27,820.10	
	$246,322.37	$250,057.26

representatives has been authorized this year as follows:

1. Seven and one-half cents per mile, one way, for each vice president of the Institute to one meeting each year of each Section and each Branch within his Geographical District, it being understood that joint meetings of Sections and Branches will be arranged as far as may be expedient.

2. Seven and one-half cents per mile, one way, for the vice president, the District secretary, the chairman of the District committee on Student activities, and either the chairman or the secretary of each Section within a District (or, if neither can attend, an alternate chosen by the executive committee of the Section) to one meeting each year of the District executive committee *held within the District*.

3. Seven and one-half cents per mile, one way, for the vice president and secretary of each District, and the counselor and the incoming Student chairman of each Branch within the District (alternates not authorized) to one conference on student activities *within the District* each year under the auspices of the committee on Student activities of the District.

4. Five cents per mile, one way, for one delegate from each Section to the annual summer convention.

5. Five cents per mile, one way, for one Student Branch counselor from each District, to represent the committee on Student activities of the District to the annual summer convention.

6. Five cents per mile, one way, to all members of the national nominating committee to the annual meeting of the committee, held during the winter convention.

It will be noted that the rate of 5 cents per mile, one way, has been retained for traveling expenses to meetings which will be held during the winter and summer conventions, when the certificate plan for a reduced return fare, and summer excursion rates, respectively, will be in effect. Similarly, the budget provides for payment of traveling expenses for attendance at the meetings of the board of directors and executive committee at the rate of 5 cents per mile, one way, for the January and June meetings and $7^1/_2$ cents per mile to all other meetings.

The recommendations of the finance committee with respect to traveling allowance were adopted by the board of directors with the understanding that the entire subject will receive further consideration by the committee, and subsequently by the board of directors at its January meeting.

OTHER ACTIVITIES

The remainder of the budget comprises those items for which further explanations, beyond a statement of the appropriation or activity, the amount expended last year, and the anticipated expense for the present year, probably are unnecessary. It will be noted that an annual contribution of $10,000 is being made to American Engineering Council. Payment of the balance of the Institute's share of the cost of new stacks for the Engineering Societies Library has been decided upon, in place of amortizing this expense over a period of 4 years, opportunity for which was afforded by United Engineering Trustees.

In the above brief presentation it has, of course, been quite impossible to describe the nature and relative importance of the various items which make up the annual budget. From an intimate knowledge of such affairs, however, the board of directors and finance committee have again endeavored to adopt a budget which places the proper emphasis on the different phases of Institute activities, and which limits the annual expenditures to the approximate total of anticipated income for the corresponding period. Obiously, the correctness of the information which has been prepared is largely dependent upon the prompt collection of annual membership dues, the chief source of Institute revenue, but with a knowledge of the excellent record of support contributed by the membership in the past, the board of directors and finance committee enter upon a new administrative year of the Institute confident that its efforts to maintain the Institute's record of services to all members and its substantial progress in the advancement of the electrical engineering profession are assured of success.

Montefiore Award for 1935 Presented

The triennial award of the George Montefiore Foundation of the University of Leeds, Belgium, has been presented for 1935 to Gabriel Kron (A'30), general engineering department, General Electric Company, Schenectady, N. Y. This prize, of 10,000 Belgian francs, was awarded for the best original work on scientific advancement and progress in technical application in any field of electricity submitted to the foundation for consideration.

The award to Mr. Kron was based upon a memoir which he entitled "Non-Riemannian Dynamics of Rotating Electrical Machinery," and submitted some time ago. Announcement of the availability of this prize was given in ELECTRICAL ENGINEERING for June 1934, page 1026. The first prize in this competition, which is international in scope, has not been awarded to an American since 1923 when it was won by Dr. J. B. Whitehead (A'00, M'08, F'12, life member and junior past-president), dean of the school of engineering, Johns Hopkins University, Baltimore, Md.

Heat Transmission Symposium to Be Held. The symposium on heat transmission to be held at Yale University, New Haven, Conn., December 30–31, 1935, under the auspices of the chemical engineering department, continues the policy inaugurated in 1934 by the division of industrial and engineering chemistry of the American Chemical Society, of holding special meetings for chemical engineering symposiums. The subject of heat transmission has been chosen for the forthcoming meeting, because of its wide appeal to chemical engineers, industrial chemists, and engineers in other fields. The tentative program includes 13 papers in the broad field of heat transfer, including heat conduction in solids, heat transfer by convection between fluids and solids, and heat transfer by radiation. Meetings will be held at the Sterling chemistry laboratory of Yale University, on Monday afternoon, December 30, Tuesday morning and afternoon, December 31. Any one interested is invited to attend whether a member of the division or not. There will probably be a small registration fee to cover the cost of preparing, in advance of the meeting, abstracts of the papers to be presented. A brief address of welcome will be given by Prof. R. E. Doherty (A'16, M'27), dean of the Yale engineering school.

American Engineering Council

A.E.C. Committees Meet in Washington

Preliminary to the annual assembly of American Engineering Council which will be held in Washington, D. C., on January 9–11, 1936, meetings of 2 of Council's committees were held in Washington, November 1 and 2, 1935.

The public affairs committee of A.E.C. met on November 1; this committee, made up of representatives of national and local societies, together with chairmen of the major subcommittees of the public affairs committee, discussed several major public policies in which engineers have an opportunity for the expression of opinion. The following subjects were included: administration of public works; development of areonautics; competition of government with engineers in private practice; development of water resources; the trend in patent legislation; and the demand for rural electrification. Approval was given to the development of complete reports on these subjects at the January meeting.

In line with Council's many actions on the basic federal survey and mapping program of the United States, it was voted that Council continue to work for a co-ordination of basic mapping activities and that such a mapping program should not be considered an emergency or relief measure, but a fundamental matter underlying any program of national planning. In the further discussion which developed around the relation of engineers to national planning, it was agreed that engineers, by their training and experience, can make contributions to social and economic as well as to technical features of planning in its national, state, and local phases.

The public affairs committee recorded itself as in complete sympathy with the efforts of the National Civil Service Reform League to establish a wider public understanding of the essential value of the merit system, and further co-operation of Council with other engineering bodies to support the merit system as the only sound basis for improvement in the technical services of the government was recommended. Also, it was proposed to co-ordinate further the work of the national, state, and local public affairs committees in order that Council, in all matters, may be truly representative as a complete cross section of the profession.

At the meeting of the executive committee of A.E.C. held November 2, the nominating committee, consisting of A. W. Berresford (A'94, M'06, F'14, member for life, and past-president) New York, N. Y., *chairman*, H. P. Eddy of Boston, Mass., and Robert W. Yarnall of Philadelphia, Pa., unanimously reported the selection of Dr. A. A. Potter, dean of the school of engineering, Purdue University, West Lafayette, Ind., as nominee for the presidency of Council for 1936–37.

United Engineering Trustees, Inc.

The Joint Engineering Organizations

United Engineering Trustees, Inc., organized in 1904, is now a joint agency of the 4 national societies representing the civil, mining and metallurgical, mechanical, and electrical engineers. It is organized in 3 departments, namely, the administrative department, The Engineering Foundation, and the Engineering Societies Library.

The administrative department manages the Engineering Societies Building and all trust funds placed in the hands of the United Engineering Trustees, Inc. The Engineering Foundation, founded by Ambrose Swasey (HM'28) in 1914, is entrusted with the expenditure of the income from endowments and other funds, its present preferred activity being engineering research. The Engineering Societies Library is a free public library which, with its numerous activities, is operated for users at a distance, as well as for those who visit its rooms in the Engineering Societies Building.

In the accompanying articles will be found announcement of the election recently held by United Engineering Trustees, Inc., and abstracts of the annual reports of this organization and of The Engineering Foundation. The recent election of The Engineering Foundation, held as part of the annual meeting on October 10, 1935, was reported in Electrical Engineering for November 1935, page 1275.

This year, 1935, marks the advancing of the dates of annual meetings and elections of both these organizations, as a result of the new by-laws, which change the end of the fiscal year from December 31 to September 30. For both of these organizations in 1935, therefore, the fiscal year was only 9 months in length. Changes in the terms of officers and trustees of United Engineering Trustees, Inc., and of officers and directors of The Engineering Foundation, have been made, as announced in Electrical Engineering for April 1935, page 457.

Election of United Engineering Trustees, Inc., Held

Officers to serve United Engineering Trustees, Inc., for the 1936 year were elected at the annual meeting of that organization held in the Engineering Societies Building, New York, N. Y., October 24, 1935. G. L. Knight (A'11, F'17) vice president in charge of mechanical operations of the Brooklyn Edison Company, Brooklyn, N. Y., was elected president of United Engineering Trustees to serve for the period ending at the annual meeting in October 1936. (A brief sketch of Mr. Knight's career is given in this issue of Electrical Engineering, page 1423.) H. G. Moulton continues in office as first vice president, having been elected last January to serve for the period ending October 1936. At the recent annual meeting, Otis E. Hovey was elected second vice president, for the term ending October 1937. John Arms was re-elected secretary, and Albert Roberts was elected to serve as assistant treasurer, both for the term ending October 1936. The resignation of C. P. Hunt as treasurer was accepted, and the nominating committee was requested to make further suggestions for the office of treasurer.

The names of all members of the board of trustees of United Engineering Trustees, Inc., including both new members and hold-over members are given in the following tabulation:

Terms expiring October 1936	
John P. Hogan	A.S.C.E. representative
H. G. Moulton	A.I.M.E. representative
D. Robert Yarnall	A.S.M.E. representative
H. R. Woodrow (A'12, F'23)	A.I.E.E. representative
Terms expiring October 1937	
Otis E. Hovey	A.S.C.E. representative
Walter Rautenstrauch	A.S.M.E. representative
Terms expiring October 1938	
J. P. H. Perry	A.S.C.E. representative
A. L. J. Queneau	A.I.M.E. representative
Harold V. Coes	A.S.M.E. representative
George L. Knight (A'11, F'17)	A.I.E.E. representative
Terms expiring October 1939	
Albert Roberts	A.I.M.E. representative
H. P. Charlesworth (M'22, F'28, and past-president)	A.I.E.E. representative

Of these, J. P. H. Perry and Albert Roberts became new members, and H. V. Coes and H. P. Charlesworth became reappointed members, of the board of trustees at the annual meeting on October 24, upon presentation of credentials from the founder societies. All others are hold-over members. Mr. Rautenstrauch is completing the unexpired term of W. L. Batt.

Committees Appointed

The following committees were appointed by the president: finance committee, Otis E. Hovey, *chairman*, H. G. Moulton, Albert Roberts, Walter Rautenstrauch, and George L. Knight (A'13, F'17) *ex-officio;* real estate committee, H. R. Woodrow (A'12, F'23) *chairman*, J. P. H. Perry, A. L. J. Queneau, and H. V. Coes.

Annual Report Issued by United Engineering Trustees, Inc.

The annual report of United Engineering Trustees, Inc., for 1935 has been submitted by Harold V. Coes, president for the term expiring September 30, 1935. The fiscal year of 1935 covered 9 months only, January 1 through September 30; this was the transition period under the new by-laws, which changed the year end from December 31 to

September 30. In consequence, all acts were based upon an apportioned budget, for comparative purposes.

U.E.T. continues as treasurer for the Professional Engineers Committee on Unemployment (of the metropolitan area of New York, N. Y.) and has recently accepted appointment as treasurer for the Engineers' Council for Professional Development.

Improvements have been made to the Engineering Societies Building, particularly to the auditorium. The public address system has been improved, as have the seating arrangements. Obsolete types of lighting fixtures have been removed from the building, and replaced by better and more efficient fixtures.

Operations of U.E.T. have been simplified in several respects under the new by-laws.

The departments of U.E.T. are reported to have remained within their budgets for the year, which are made on a most conservative basis. Changes have been made in mortgages and other investments held, to the advantage of the corporation. A summary of the report of the finance committee of the corporation for 1935 appears in table I. If this tabulation is compared with the similar one for the preceding year which appeared in ELECTRICAL ENGINEERING for April 1935, page 458, it should be noted that the accompanying tabulation for 1935 does not include the founder societies' interest in the library, which, it is reported, was appraised at $480,800 in the year 1933. The aggregate book value of the investments included in the accompanying tabulation is $1,351,380.60 at September 30, 1935, and the aggregate valuation based upon market quotations on that date is $1,283,617.

Annual Report Issued by Engineering Societies Library

The annual report of the Engineering Societies Library for the period January 1 to September 30, 1935 has been submitted by Harrison W. Craver, director. It contains information on the use made of the library, its acquisitions and finances.

The number of users was 30,289, approximately the same as for the first 9 months of 1934. Of these, 22,399 were readers in the library, the remaining 7,890 being nonvisitors who contacted the library by mail or telephone. One hundred and ten searches and 90 translations were made and 128 books were lent to 114 members. There were orders from 1,671 persons for photoprints, requiring the taking of 13,214 photographs. Letters were written answering inquiries from 2,298 persons and 3,606 were assisted by telephone.

An interesting tendency is the increasing use of the library as a general intelligence office, or information bureau. Also, there was a large increase in the number of translations during the year, the number of works translated during the 9 months ending September 30, 1935, being slightly greater than that during the preceding 12 months.

Through purchase and gifts 7,877 items, consisting of books, pamphlets, and maps, were acquired. Of these, 5,180 pieces were not already in the collection. The current numbers of 1,353 periodicals were received, and 273 volumes, worth approximately $1,000, were sent by publishers for review.

Gifts amounted to 6,787 items. Among these were gifts from the estates of Axel O. Ihlseng, Calvin W. Rice, H. de B. Parsons, and John W Lieb. Valuable gifts also were received from R. A. Lesher, George C. Stone, R. W. Seabury, the Huntington Free Library Reading Room, the Parsons Steam Turbine Company, and the Amkniga Company.

On January 1, the library contained 134,344 books, 6,965 maps, and 4,241 manuscript bibliographies, or searches. The corresponding figures on September 20 were 136,464 books, 7,064 maps, and 4,259 searches. In addition 2,741 pamphlets were added to volumes which had been accessioned previously. The loan collection contained 815 volumes on September 30, and there were approximately 11,500 duplicate books on hand. All new material has been cataloged, many improvements in the catalog having been made.

During the 9 months, 17,389 references were added to the classified index to periodical literature, a greater number than in the 12 months of 1934. This was accomplished without any increase in staff. The index now contains about 132,000 cards, and has become a valuable guide to recent literature.

The budget for general operations during the calendar year 1935 as adopted by the trustees and the founder societies, was $42,800. Of this amount $33,300.10 consisted of appropriations by the founder societies, as follows:

American Society of Civil Engineers	$8,725.80
American Institute of Mining and Metallurgical Engineers	6,780.96
American Society of Mechanical Engineers	8,900.04
American Institute of Electrical Engineers	8,893.30

Expenditures for the 9 months amounted to $30,612.71. For work done by the service bureau $5,834.34 were received; the expenses of the bureau were $4,059.85.

Table I—Summary of U.E.T. Finance Committee Report for 1935

Operation of Building			
Operating revenue			$75,845.42
Less operating expenditures			72,635.51
Operating gain 1935			3,209.59
Operating credit previous years			1,667.23
1934 expenditure charged to depreciation and renewal fund in 1935			542.56
Credit balance Sept. 30, 1935			$ 5,419.70
Operation of Library			
Maintenance revenue		$32,194.57	
Maintenance expenditures		31,358.04	
Credit balance for year 1935		836.53	
Credit balance from previous year		$ 3,697.83	
Credit balance Sept. 30, 1935			$ 4,534.36
Service bureau revenue		$ 5,834.34	
Service bureau expenditures and adjustments		4,090.20	
Credit balance Sept. 30, 1935			$ 1,744.14
Total net operating credit balance cumulated to Sept. 30, 1935			$ 6,278.50
Funds and Property			
Funds Included:		**Book Value**	**Market Value**
Engineering Foundation fund		$ 783,132.74	
Edward Dean Adams fund		100,000.00	
Library endowment fund		174,544.32	
Depreciation and renewal fund		336,992.38	
General reserve fund		0.00	
Total		$1,394,669.44	
Less deferred charge—sale of securities		75,095.76	
		$1,319,573.68	
Total investment Sept. 30, 1935	$1,290,277.47		$1,235,215.00
Loans from depreciation and renewal fund	7,516.66		
Cash uninvested	21,779.55		
Total (see above)	$1,319,573.68		
Net loss on sale of securities	75,095 76		
Total (see above)	$1,394,669 44		
Real estate, cost of—Sept. 30, 1935		$1,987,793.92	
Operating cash		13,106.20	
Investments, operating cash		5,000.00	$ 4,978.00
Prepaid fire insurance		3,010.39	
Accounts receivable, gross		1,015.87	
The Engineering Foundation—unexpended income		25,372.17	
The Engineering Foundation—temporary investment		6,180.00	$ 6,300.00
Alloys of iron research —unexpended income		5,118.15	
The Engineering Foundation custodian fund assets		909.51	
Henry R. Towne engineering fund		50,000.43	$ 37,124.00
Total		$3,417,080.32	
Endowment committee (Adams Expense Fund)		$ 702.57	
John Fritz Medal Fund (Custodian)			
Securities held Sept. 30, 1935		$ 3,500.00	$ 3,430.00
Cash on hand Sept. 30, 1935		142.80	

Annual Report Issued by Engineering Foundation

The annual report of The Engineering Foundation for 1935, which this year includes the 9 months ending September 30, has been submitted by H. P. Charlesworth (M'22, F'28, and past-president) chairman of the Foundation, and Dr. Alfred D. Flinn, director.

A summary of the capital funds of The Engineering Foundation is as follows:

Endowments, total book value on September 30, 1935	$882,000
E. H. McHenry bequest, in hands of executors during lives of 2 beneficiaries, as appraised in 1931, approximately	400,000

A condensed financial statement of Foundation for the 9 months ending September 30, 1935, follows:

Resources		
Balance January 1, 1935		$21,781
Receipts		
Income from endowment and temporary investment of income balance	$26,906	
Income from minor items	663	27,569
Total resources		$49,350
Expenditures		
Research projects	$11,300	
Promotion of research and administrative expenses	6,698	
Total for furtherance and support of research		$17,998
Balance October 1, 1935		$31,352

Money contributions from organizations and individuals, for specific activities, passed through the Foundation's accounts from its organization to September 30, 1935, totaled $232,726.

Activities aided by Foundation during the 9 months ending September 30, 1935, included:

1. Continuation of the earths and foundations research, conducted by the American Society of Civil Engineers.

2. Continuation of the alloys of iron research, and the barodynamic research, both sponsored by the American Institute of Mining and Metallurgical Engineers.

3. Experimental studies of critical pressure steam boilers, boiler feed waters, effect of temperature on properties of metals, cottonseed processing, strength of gear teeth, and cutting of metals, conducted by The American Society of Mechanical Engineers.

4. A fundamental study of pure iron electrodes, in connection with welding, sponsored by the American Institute of Electrical Engineers.

5. Organizing and planning a comprehensive program for research in all branches of welding, sponsored by the American Institute of Electrical Engineers and the American Welding Society jointly.

6. Research projects of the Engineers' Council for Professional Development dealing with the accrediting of engineering schools, aptitude tests, self-appraisal methods for junior engineers, and evaluation of professional qualifications.

7. Studies by Personnel Research Federation of conference methods for dealing with employer-employee relations.

8. Research in the plastic behavior of concrete, at the University of California.

9. Investigation of the plasticity of metals, especially creep and relaxation, under the auspices of the University of Pittsburgh.

The policies of Foundation are stated in a platform adopted by its board June 14, 1935, and approved by United Engineering Trustees, Inc., and the founder societies. This platform includes a statement of the general plan and policy to be followed in assisting research projects which it approves. Information on Foundation and its activities can be obtained from its office, 29 West 39th Street, New York, N. Y.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Registration of Engineers

To the Editor:

In the October 1935 issue of ELECTRICAL ENGINEERING, on page 1129–30, I noted the comments on the registration of engineers by one of our members over at Lynn, Mass.

In the first paragraph of his comments, he speaks about the "intolerable burden on this country" which would be created by the registration of engineers as well as how "unbearably oppressive" as is such a movement. I wonder if this is a local condition or whether it is an individual idea. In this particular write-up he speaks for the whole country. In this State I know that such is not the case.

In his reference to the constant pressure of political influence on the board of examiners, I wonder if the medical, legal, and dental professions didn't encounter the same thoughts in their early stages of organization. Yet today we must admit that political influence doesn't enter into a doctor, dentist, or lawyer getting his license to practice. These professions have made an outstanding success of keeping politics out of their organization. I would hate to think that the engineers couldn't do the same.

There is no percentage in getting into a controversy with anyone on his expression of thoughts, on how he feels in such matters. However, I do feel the licensing of engineers is here. It is here to stay by virtue of the fact that it is a law in the majority of states. Whether engineers like it or not, the thing for us to do is to get in there and do our bit to see that such is taken care of in accordance with our ideas. One must not lose sight of the fact that it is a take and give proposition and you can't be a kid and have your own way all the time. One very obvious fact is that the licensing of the engineers has at least disturbed the slumbering of a large majority of them to the point where they are either talking to or about themselves. The other professions have found it necessary to change their status, codes, and ethics to conform with the present day trend. The engineer must realize that he has got to keep advance of the time or he will be more obsolete than ever. Common sense still plays a very important part in the elevation of any profession. There are too many successful engineers to allow the theory or the narrow paths of some of the few to successfully govern the profession as a whole.

The above are my personal opinions based on my experience gained from contacting engineers in a large portion of the U. S. A. It wasn't necessary for me to consult any members of any organization in making these comments.

Very truly yours,

J. LEO SCANLON (A'28, M'34)
J. Leo Scanlon Co.,
Sales Engineers
Ellicott Sq. Bldg.
Buffalo, N. Y.

Similarity Relations in Electrical Engineering

To the Editor:

There was recently published a paper "Similarity Relations in Electrical Engineering," by J. G. Brainerd and Jacob Neufeld (ELECTRICAL ENGINEERING, March 1935, pages 268–72), and subsequently a letter from Professor Weber (June 1935, pages 683–4) pointing out the necessity for inclusion of the quantities μ and K in any complete discussion of electrical dimensions.

No matter how frequently μ and K may be equated to unity and pushed out of sight, they always seem to bob up again and to inject into the discussion a perpetual query as to their nature.

It has frequently been shown (by equating the electromagnetic and electrostatic dimensional formulas for any one unit), that the quantity $\frac{1}{\sqrt{\mu K}}$ has the dimensions (LT^{-1}) of a velocity, and further that it is numerically equal to the velocity of propagation of light or electromagnetic waves in vacuum.

The dimensional equation

$$\frac{1}{\sqrt{\mu K}} = LT^{-1}$$

or, rearranged,

$$\mu = L^{-2}T^2K$$

prohibits the possibility of μ and K being, simultaneously, fundamental quantities, since, if K be taken as fundamental, μ

immediately has dimensions in L and T, and *vice versa*.

While no proof has ever been established, there is thus no prima facie reason why both μ and K should not be translatable in terms of the fundamental dimensions L, M, and T.

The equation for the velocity of propagation of a wave in an elastic medium,

$$V = \sqrt{\frac{E}{\rho}}$$

where E is elasticity and ρ is density, has been used by some writers (*e. g.*, T. F. Wall) to suggest, by analogy with the equation,

$$V = \sqrt{\frac{1}{\mu K}}$$

that μ might possibly be a measure of the density of the universal medium (whether or not modified by the presence of matter), and $1/K$ a measure of its elasticity.

It is interesting to push this suggestion to its logical conclusion by substituting $L^{-3}M$, the dimension of a density, for μ (or $LM^{-1}T^2$ for K) in the usual dimensional formulas.

At once all fractional indices disappear, while certain of the units reduce to dimensions which are, to say the least, suggestive.

Electric strain (D) of EM dimension $L^{-3/2}M^{1/2}\mu^{-1/2}$, reduces to zero dimension, the same as a mechanical strain.

Current (i), $L^{1/2}M^{1/2}T^{-1}\mu^{-1/2}$, resolves into L^2T^{-1}, suggesting diffusion.

Electromotive force (E), $L^{3/2}M^{1/2}T^{-2}\mu^{1/2}$, reduces to MT^{-2}, which may be interpreted as force per unit length.

Electric charge (Q), $L^{1/2}M^{1/2}\mu^{-1/2}$, becomes L^2, the dimension of a surface (electric charge resides *on* the surface of a conductor).

While resistivity (ρ), $L^2T^{-1}\mu$, reappears as $L^{-1}MT^{-1}$, with the same dimension as viscosity.

The foregoing is, of course, purely fanciful, and doubtless the ancient cry will be raised "Don't try to find a mechanical explanation for electrical phenomena."

There is no such intention, except in so far as mechanical, electrical and other phenomena may, at some future date, be found susceptible of a common explanation.

It is quite within the bounds of possibility that, in the working out of such a "common explanation," not only may μ and K be reduced to terms of L, M, and T, but further, the so-called fundamental M may be resolved into still more fundamental terms.

Very truly yours,

ERIC R. COBE (A'29)
915 Far Hills Avenue,
Dayton, Ohio

Capacitor Motor With Double Cage Rotor

To the Editor:

The "Letter to the Editor" by A. F. Puchstein in the September 1935 issue of ELECTRICAL ENGINEERING, page 1018, of the possibilities of the double squirrel cage rotor in capacitor motors, involves the reactions of a squirrel cage in a single phase field.

The use of the double squirrel cage or its equivalent in capacitor motors has been proposed by Steinmetz and also Professor Bailey. A practical consideration of the problem indicates the handicaps that have prevented its use in general purpose motors.

The action of a squirrel cage rotor in a single phase field is quite different from its action in a polyphase, or true rotary field. With a single phase field, the squirrel cage in addition to carrying the mechanical load also transforms the alternating field to a rotary field. The effectiveness of this transformation depends upon low resistance and high mutual inductivity of the squirrel cage. With the double squirrel cage neither element is very effective. The high resistance, or starting component, having high resistance is ineffective due to its resistance, and the low resistance, or running component, is also ineffective due to its low mutual induction. Thus, with the double squirrel cage, the transformation of the alternating field into a rotary is imperfect, and as a squirrel cage is efficient only in a substantially rotary field; its efficiency in the single phase field is lower than in a polyphase field.

While the capacitor field has a rotary component independent of the rotor reactions which may be substantially rotary at one particular load condition, in practice, under the varying conditions the squirrel cage is still called upon to stabilize, and in a material measure generate the rotary field.

Further, since the low resistance, or load carrying component of the squirrel cage has high magnetic leakage, the power factor is lowered, thereby nullifying in part the capacitor effect, requiring larger capacitor.

This magnetic leakage also requires a higher primary flux, which in turn, calls for either a higher flux density with increased iron losses, or increased magnetic structure with increased cost. As the double squirrel cage introduces a lagging component, and is also less effective in producing a rotary field, it is antagonistic to best running characteristics.

Where it is required of the capacitor motor to have exceedingly high starting torque and especially if low starting current is desirable, together with low slip at running speed, the most logical solution seems to be the repulsion starting capacitor motor.

The capacitor field with a capacitor suitable for running conditions is predominantly single phase under starting conditions. This makes it possible to utilize the repulsion starting rotor the same as used in repulsion starting induction motors, with the same high torque and low starting current, characteristic of repulsion starting induction motors.

Very truly yours,

EDWARD BRETCH (M'19)
The Advance Electric Co.,
St. Louis, Mo.

Personal Items

F. V. MAGALHAES (A'07, F'19) for the past year connected with the inventory of the properties of the Consolidated Gas Company, New York, N. Y., and previously with the General Electric Company at West Lynn, Mass., has been appointed assistant to the executive vice president of the New York (N. Y.) Edison Company, Inc. Mr. Magalhaes, who received the degree of electrical engineer from Brooklyn (N. Y.) Polytechnic Institute in 1906, has already had many years of experience with the New York Edison Company. After several short periods of employment with the company, alternated with school and other work, he entered the meter department in 1907, becoming superintendent 2 years later. In 1917 he was made superintendent of the test department also. From 1926 to 1928 he was general superintendent of distribution and installation, leaving the company to become vice president for engineering of the Hall Electric Heating Company. This company was liquidated voluntarily in 1932, at which time Mr. Magalhaes became commerical representative for the General Electric Company at West Lynn. He is now a member of the Institute's standards committee and of the committee on safety codes, of which he was chairman 1928–29 and 1932–34. He has been a member of the board of examiners since 1931, serving previously 1923–28, since 1928 has been Institute representative on the electrical committee of the National Fire Protection Association, and since 1930 has been representative on the National Fire Waste Council, previously serving for the year 1928–29. Mr. Magalhaes also has been active in the work of other organizations, and for some years was secretary and vice president of the U.S. national committee of the International Electrotechnical Commission.

GABRIEL KRON (A'30) general engineering department, General Electric Company, Schenectady, N. Y., has received the 1935 award of the George Montefiore Foundation of the University of Liege, Belgium, for his

GABRIEL KRON

G. L. KNIGHT

memoir entitled "Non-Riemannian Dynamics of Rotating Electrical Machinery." Mr. Kron, who was born in 1901 at Nagybanya, Hungary, came to the United States after having studied in Europe for several years. In 1924 he received the degree of bachelor of science in electrical engineering from the University of Michigan. Following several months during 1924 in the machine shop of the U.S. Electrical Manufacturing Company, Los Angeles, Calif., he became draftsman for the Jeannin Electric Company, Toledo, Ohio. Between 1925 and 1927, he was designer for the Robbins and Myers Company, Springfield, Ohio. In 1928, he was engaged in research for the Lincoln Electric Company, Cleveland, Ohio, and then became consulting engineer for the United Research Corporation, Long Island City, N. Y. Subsequently, he joined the organization of the General Electric Company, where he is now engaged. Mr. Kron is the author of numerous papers on tensor analysis.

B. W. Kerr (A'12) president and general manager, Railway and Industrial Engineering Company, Greensburg, Pa., was recently elected first vice president of the National Electrical Manufacturers Association. Mr. Kerr, a graduate of Princeton University, was employed by the Westinghouse Electric and Manufacturing Company and the Pittsburgh Railways Company before he came to the Railway and Industrial Engineering Company as assistant manager in 1910. He was vice president and general manager of the company from 1914 until 1918, when he became president. He is also president of the Electrical Development and Machine Company and the Kirk Interlock Company, both of Greensburg.

G. L. Knight (A'11, F'17, and past vice president) vice president in charge of mechanical operations, Brooklyn Edison Company, Inc., Brooklyn, N. Y., has been elected president of United Engineering Trustees, Inc., for the term ending October 1936. He also becomes an *ex-officio* member of the board of The Engineering Foundation. Mr. Knight, who was born at Haddonfield, N. J., graduated from the school of electrical engineering at Drexel Institute in 1900, and came to the Brooklyn Edison Company in 1905 as chief draftsman, having had a similar position previously with the New York Edison Company. In 1908 he was appointed designing engineer, and held this position until his appointment as mechanical engineer in 1924. Since 1932 he has been vice president. Mr. Knight, who has just completed serving as vice president of United Engineering Trustees, Inc., and as chairman of its finance committee, has been a representative of the Institute on the board of U.E.T. since 1933, having had a previous term 1926–31. He has served on many Institute committees, and was a manager 1922–26 and a vice president 1926–28. He is also a member of The American Society of Mechanical Engineers.

M. T. Crawford (A'07, F'22) who has been general superintendent in the central district of the Puget Sound Power and Light Company, Seattle, Wash., has been appointed assistant chief engineer in the newly enlarged engineering department, which will handle engineering for all districts and divisions of the company. Mr. Crawford, who was born at Louisville, Ky., received from the University of Washington the degrees of bachelor of science in electrical engineering in 1907 and master of science in electrical engineering in 1910. From 1906 to 1912 he was connected with the Seattle-Tacoma Power Company, becoming assistant engineer, and in 1912 accepted the position of superintendent in the water power department of the Puget Sound Traction, Light, and Power Company, which later became the Puget Sound Power and Light Company. He held successively the positions of superintendent of transmission and distribution divisions in the former company, and superintendent of distribution and general superintendent in the latter company. Mr. Crawford was a member of the Institute's committee on power transmission and distribution during 4 periods: 1916–17, 1919–20, 1924–26, and 1927–29.

E. W. Schilling (A'29, M'33) assistant professor of electrical engineering at Michigan College of Mining and Technology, Houghton, has been appointed associate professor. Doctor schilling, who received the degree of bachelor of science in electrical engineering from the University of Illinois in 1919, received the degrees of master of science in electrical engineering and doctor of philosophy in 1930 and 1933, respectively, from Iowa State College, where he was a member of the faculty from 1928 to 1931. He had previously been connected with the General Electric Company, Schenectady, N. Y., the B. F. Goodrich Rubber Company, Akron, Ohio, and E. W. Schilling and Company, Brandon, S. D. Doctor Schilling has been at the Michigan College of Mining and Technology since 1931.

H. A. Johnson (M'17) general manager, Chicago Rapid Transit Company, Chicago, Ill., has received the honorary degree of doctor of engineering from Purdue University, where he was graduated in 1905. Mr. Johnson has been employed by the railway company since 1905, and recently served as director of research for the mechanical engineering division of the American Railway Association, supervising tests to develop an improved type of air braking equipment. He is also a member of the Western Society of Engineers, and at one time was a member of the Institute's committee on transportation.

H. P. Charlesworth (M'22, F'28, and past-president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y., has been elected chairman of the John Fritz medal board of award. Mr. Charlesworth has been a representative of the Institute on the board since 1932, and is now a member of the Edison medal, code of principles of professional conduct, and Institute policy committees of the Institute, as well as representative of the Institute on the board of trustees of United Engineering Trustees, Inc. In the past he has served on numerous committees and was president of the Institute 1932–33.

E. F. Pearson (M'20) who has been assistant chief engineer of the Northwestern Electric Company and Pacific Power and Light Company, Portland, Ore., has been made chief engineer of the Northwestern Electric Company. Mr. Pearson, a graduate of the University of Nevada, became assistant engineer of this company in 1913, and assistant superintendent of construction the following year. In 1919 he was made electrical engineer. During the year 1933–34 he was a member of the Institute's membership committee.

J. L. Dalton (A'35) has been awarded the A.I.E.E. scholarship for 1935–36, and is now studying at Columbia University, New York, N. Y., as announced in Electrical Engineering for November 1935, page 1274. Mr. Dalton was born at Glenside, Pa., March 19, 1912, and received the degree of bachelor of science at Pennsylvania State College in 1934. He was then employed in the electrical engineering department of the Reading Railway Company until the awarding of the scholarship.

H. E. Boatright (A'12, M'29) former division manager for the Guanajuato Power and Electric Company, Guanajuato, Mexico, has been made superintendent of operation. Mr. Boatright, who received the degree of bachelor of science in electrical engineering at Colorado College in 1907, has been with the company since 1924, when he became meter superintendent, 3 years later being made superintendent of maintenance and operation.

A. W. Berresford (A'94, F'14, member for life, and past-president) has been appointed Institute representative on the John Fritz medal board of award to fill the unexpired term, ending in October 1938, of the late J. Allen Johnson (A'07, F'27, and junior past-president). Mr. Berresford is also a member of the committees on Institute policy and safety codes.

Gerard Swope (A'99, F'22, and member for life) president, General Electric Company, New York, N. Y., has been elected a member of the board of governors of the Na-

tional Electrical Manufacturers Association. Recently he was elected a trustee of the New York Museum of Science and Industry. Mr. Swope was a member of the Institute's Iwadare Foundation committee 1931–35.

W. B. Tuttle (M'30) who has been president of the San Antonio Public Service Company since 1922, is now chairman of the board of directors of the company. Mr. Tuttle has been connected with the company since 1906, serving as vice president and general manager from that year until his appointment as president.

F. S. Benson (A'28) assistant electrical engineer in the department of engineering, Pacific Gas and Electric Company, San Francisco, Calif., received second prize for his paper suggesting standardization in a contest conducted by *Electrical West* on the question of how distribution costs could be lowered.

G. W. McCracken (A'22) who has been electrical engineer with the Birmingham Electric Company, Birmingham, Ala., has been appointed chief engineer. Mr. McCracken is a graduate of Kansas State Agricultural College, and was employed by electric companies in Cuba before coming to the Birmingham Electric Company in 1927.

F. B. Jewett (A'03, F'12, and past-president) vice president, American Telephone and Telegraph Company, and president, Bell Telephone Laboratories, Inc., has been elected president of the New York Museum of Science and Industry. Doctor Jewett is serving on several committees of the Institute.

P. R. Moses (A'94, F'12) electrical engineer, head of the firm of Percival R. Moses, New York, N. Y., is one of the incorporators of Electric Plant Owners Association, Inc., formed to unite the owners and operators of private plants in the city and state of New York.

E. B. Meyer (A'05, F'27, and president) has been appointed to serve as a special representative on the visiting committee of the department of electrical engineering of Massachusetts Institute of Technology for the academic year beginning October 1935.

S. L. Nicholson (A'00, F'13) assistant to vice president and general manager, Westinghouse Electric and Manufacturing Company, New York, N. Y., has been elected a vice president of the National Electrical Manufacturers Association.

W. D. Steele (A'00 and member for life) president, Benjamin Electric Manufacturing Company, Des Plaines, Ill., has been elected a member of the board of governors of the National Electrical Manufacturers Association.

W. J. Kidd (A'24, M'32) is now switchboard design engineer with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He was formerly assistant system planning engineer for the Pennsylvania Power and Light Company.

C. L. Collens, 2d (A'07) president, Reliance Electric and Engineering Company, Cleveland, Ohio, has been elected a member of the board of governors of the National Electrical Manufacturers Association.

V. G. Dodds (A'26) Aluminum Company of America, is at Los Angeles, Calif., and not at San Francisco as announced in Electrical Engineering for November 1935, page 1281.

E. O. Shreve (A'06) assistant vice president, General Electric Company, Schenectady, N. Y., has been elected a vice president of the National Electrical Manufacturers Association.

H. R. Arnold (A'31) recently in the forestry service of the U.S. Department of Agriculture, is now transformer design engineer with the Westinghouse Electric and Manufacturing Company, Sharon, Pa.

J. F. Imle (A'32) geophysical engineer, has left the Humble Oil and Refining Company, Houston, Tex., and is with Lago Petroleum Corporation, Maracaibo, Venezuela.

P. H. Pierce (A'12, M'27) former engineer with Electrical Research Products, Inc., New York, N. Y., is now an engineer in the Bell Telephone Laboratories, Inc., New York.

A. B. Berresford (A'31) who recently received the degree of doctor of medicine from the Boston University School of Medicine, is now an interne at Waterbury Hospital, Waterbury, Conn.

A. H. Heitzler (M'24) superintendent of electrical department, Public Service Company of Colorado, Denver, has been elected a vice president of the Rocky Mountain Electrical Association.

W. C. Sterne (A'23, M'32) president and general manager, Arvada Electric Company, Denver, Colo., has been elected a vice president of the Rocky Mountain Electrical Association.

J. A. Wood, Jr. (A'30) who recently received the degree of doctor of philosophy from Cornell University, is now an instructor in electrical engineering at Massachusetts Institute of Technology.

W. L. Sullivan (A'34) who has been an instructor in the department of electrical engineering at Massachusetts Institute of Technology at Cambridge, is now at Stevens Institute of Technology, Hoboken, N. J.

S. H. Magruder (A'34) formerly employed by the U.S. Coast and Geodetic Survey, is now in the business training course of the General Electric Company at Schenectady, N. Y.

J. R. Seckman (A'20) former sales engineer for the International Machinery Company at Santiago, Chile, is now senior engineer for the State Road Commission of West Virginia, Clarksburg.

H. M. Platt (A'24) formerly with the National Electrical Manufacturers Association, New York, N. Y., is now secretary and treasurer of the Batavia Times Publishing Company, Batavia, N. Y.

F. H. Collins (M'31) former operations supervisor for the United Power and Light Corporation at Abilene, Kan., is now fire alarm superintendent for the city of Wichita.

T. N. Racheff (A'33) former supervisor for C. F. Burgess Laboratories, Madison, Wis., is now with the Commonwealth Edison Company, Chicago, Ill.

R. E. Thornton (M'32) formerly resident engineer at Sapulpa, Okla., for the Oklahoma Gas and Electric Company is now division engineer at Fort Smith, Ark.

R. H. Croll (A'28) formerly in the industrials division of the Worthington Pump and Machinery Company at Harrison, N. J., has been transferred to Buffalo, N. Y.

Obituary

Edwin Wilbur Rice, Jr. (A'87, F'13, HM'33, past-president and member for life) died November 25, 1935, as this issue of Electrical Engineering was going to press. A biographical sketch of Doctor Rice is scheduled for inclusion in the next issue.

Dudley Hyde Keyes (A'19) structural protection engineer, Bell Telephone Laboratories, Inc., New York, N. Y., died November 9, 1935. He was born December 17, 1883, at Eau Claire, Wis., and was a graduate of the electrical engineering course of the University of Wisconsin. He entered the engineering department of the Chicago Telephone Company in 1906, and in 1912 became an engineer with the Michigan State Telephone Company. Four years later he entered the engineering department of the American Telephone and Telegraph Company at New York, and recently was transferred to the Bell Telephone Laboratories, Inc., as assistant protection engineer. Mr. Keyes was chairman of the structural coordination committee of the Edison Electric Institute, and was the author of a recent A.I.E.E. paper.

Arthur J. Pates (A'25, M'27) telephone engineer, Chesapeake and Potomac Telephone Company, Baltimore, Md., died September 2, 1935. He was born at Boston, Mass., November 5, 1877, and studied electrical engineering at Harvard University. From 1904 to 1913 he was employed in the engineering department of the New York Telephone Company, and since 1913 had been in the engineering department of the Chesapeake and Potomac Telephone Company at Washington, D. C., and Baltimore,

where he was in responsible charge of the engineering of telephone plant equipments.

Allen Harwood Babcock (A'04, F'12, and past vice president) retired, Inverness, Calif., died October 26, 1935. He was born at Buffalo, N. Y., August 12, 1865, and studied at Lehigh University and at the University of California. In 1891 he was employed as draftsman by the Thomson-Houston Electric Company in San Francisco, Calif., and the following year was made assistant engineer; this company was a predecessor of the General Electric Company. In 1898 he took a similar position with the Standard Electric Company of California, becoming superintendent the following year. He then held the position of electrical engineer, successively, with the California Gas and Electric Company, North Shore Railroad, and Southern Pacific Company. During this time he was engaged in electrical traction work, and is credited with making the first installation of third rail electrification in California. He retained his position with the Southern Pacific Company until his retirement in 1932, serving also as consulting engineer for affiliated companies. He was a vice president of the Institute 1918–19, and was a member of the committees on traction and transportation, 1914–22; lighting and illumination 1920–21; and code of principles of professional conduct, 1915–35. He was a member of a number of organizations, and was the author of many professional papers.

Membership

Recommended for Transfer

The board of examiners, at its meeting held November 13, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Baker, Horatio O., engr., N. Y. State Pub. Serv. Comm., Buffalo, N. Y.
Barr, Rowland W., E.E., Braden Copper Co., Rancagua, Chile, S.A.
Bauer, William M., instr. in E.E., Northwestern Univ., Evanston, Ill.
Brownlie, Wm. N., engr., Mutual Boiler Insurance Co. of Boston, Mass.
Campkin, Wilbert L., equipment supervisor, Saskatchewan Government Telephones, Regina, Sask., Can.
Copeland, Robert M., contracting E.E., Copeland Elec. Co., Jersey City, N. J.
Crawford, Fred D., supervisor, Brooklyn Edison Co., Brooklyn, N. Y
Devine, Perle A., elec. tester, Public Service Co. of No. Illinois, Chicago.
Esty, Edward S., distrib. supt., Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
Hallenbeck, C. S., office mgr., long lines engg. dept., Am. Tel. & Tel. Co., New York, N. Y.
Honaman, R. Karl, protection methods engr., Bell Tel. Labs., Inc., New York, N. Y.
Kester, Harold J., sales engr., Westinghouse Elec. Mfg. Co., St. Louis, Mo.
Laidlaw, Hugh A., asst. engr. of operation, Pacific Gas & Elec. Co., San Francisco, Calif.
Ogur, Eugene, cons. E.E. and M.E., Newark, N. J.
Oman, Carl, E.E., Westinghouse Elec. and Mfg. Co., Newark, N. J.
Pfeil, Walter W., engr., Public Service Elec. and Gas Co., Newark, N. J.
Rice, Cortis N., valuation engr., Byllesby Engg. and Mgt. Corp., Chicago, Ill.
Tomlinson, Henry R., engr., New England Power Engg. and Service Corp., Worcester, Mass.

18 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Dec. 31, 1935, or Feb. 28, 1936, if the applicant resides outside of the United States or Canada.

Anderer, J., N. Y. Hospital, New York, N. Y.
Arthur, R. S., Gen. Elec. Co., Phila., Pa.
Arutunoff, A. (Member), Reda Pump Co., Bartlesville, Okla.
Beatty, R., Union Elec. Lt. & Pwr. Co., St. Louis Mo.
Berry, E. W. (Member), State Trade Sch., Stamford, Conn.
Blackmore, A. H., Westinghouse Elec. & Mfg. Co., Houston, Texas.
Brown, H. F., N. Y. Hospital, New York, N Y.
Bruce, H. W., Dept. of Water & Pwr., City of Los Angeles, Calif.
Bruning, A. C., Columbus Ry. Pwr. & Lt. Co., Ohio.
Buehner, R. O. (Member), Am. Steel & Wire Co., Waukegan, Ill.
Chirgwin, W. C., Pub. Serv. Elec. & Gas Co., Newark, N. J.
Couts, F. H. (Member), Consumers Pwr. Co., Jackson, Mich.
Cramer, H. W., 109 Cumberland St., Brooklyn, N. Y.
Davies, F. H. (Member), Detroit Edison Co., Mich.
Davis, C. R., San Francisco–Oakland Bay Bridge, San Francisco, Calif.
Demmings, H. L., Lynn Gas & Elec. Co., Lynn, Mass.
Diefandahl, W. F., Brooklyn Edison Co., Brooklyn, N. Y.
Dobric, F. S., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Duarte, P. J., Jr., 2a, Chiapas No. 31, Mexico, D. F., Mexico
Dye, L. E., Los Angeles Railway Corp., Calif.
Eby, J. B. (Member), Am. Tel. & Tel. Co., Phila., Pa.
Eckles, L. B., Consumers Pwr. Co., Jackson, Mich.
Edwards, F. E. (Member), N.Y. Central R. R. Co., Harmon-on-Hudson, N. Y.
Eighmy, L. W., Jr., Buffalo Gen. Elec. Co., N. Y.
Ellis, S. G., Westinghouse E. & M. Co., Chicopee Falls, Mass.
Endicott, H. S., Gen. Elec. Co., Pittsfield, Mass.
Escobosa, C. W , Pub. Util. Consolidated Corp., Nogales, Ariz.
Finley, K. G., Wash. Water Pwr. Co., Spokane.
Gager, F. M., Boston Col., Chestnut Hill, Mass.
Gallagher, J. P., N. Y. Pwr. & Lt. Corp., Schenectady, N. Y.
Galt, O. P., Ga. Pwr. Co., Canton.
Germeck, C. W., Gen. Elec. Co., Pittsfield, Mass.
Gersoni, H. B., Camp Lower Cispus F-34, Randle, Wash.
Golden, C. H., Texas Elec. Service Co., Ft. Worth.
Haas, H. (Member), Consumers Pwr. Co., Jackson, Mich.
Hahnloser, R. G., Gen. Elec. Co., Lynn, Mass.
Hall, W. G., Una Welding Inc., Cleveland, Ohio.
Hamilton, L. G., Gen. Elec. Co., Pittsfield, Mass.
Hardie, J. B., Jr., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Hartwell, L. M., Jr., Am. Tel. & Tel Co., St. Louis, Mo.
Hedger, G. L., Canadian Gen. Elec., Fraserdale, Ont., Can.
Hissett, W. H. (Member), Sawbrook Steel Castings Co., Lockland, Ohio.
Hoag, S. B. (Member), Titanium Pigment Co., Sayreville, N. J.
Howard, G. A., Consumers Pwr. Co., Jackson, Mich.
Hutson, A. D., City of Gainesville, Fla.
Isom, C. W., Southwestern Bell Tel. Co., Dallas, Texas.
Jamison, W. M. (Member), Am. Tel. & Tel. Co., Chicago, Ill.
Jennings, A. S., Arma Engg. Co., Inc., Brooklyn, N. Y.
John, G. J., 1549 West St., Utica, N. Y.
Kazmierski, V. C., N. Y. Hospital New York, N. Y.
Kendall, E. H. (Member), Consumers Pwr. Co., Jackson, Mich.
Key, W. A., Box 44, France Field, C. Z.
King, E. D. (Member), Detroit Edison Co., Mich.
King, G. L., Okla. Gas & Elec. Co., Okla. City.
Knox, J. P., N. Y. Hospital, New York, N. Y.
Kornfeld, LeR., Kansas City Pwr. & Lt. Co., Kansas City, Mo.
Lehman, M. L. (Member), Am. Tel. & Tel. Co., Phila., Pa.
Leonardon, E. G., Schlumberger Well Surveying Corp., Houston, Texas.
Le Vesconte, L. B., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Levine, M., Amdur Leather Co., Danvers, Mass.
Lewis, G. E., Vernon Lt. & Pwr. Co., Vernon, Calif.
McCord, O. P., Westinghouse E. & M. Co., New Orleans, La.
Mehr, C. A., 41 Derby Ave., Seymour, Conn.
Morris, R. C., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Morton, A. R., Globe Union Mfg. Co., Milwaukee, Wis.
Muller, C. A. (Member), Am. Gas & Elec. Co., New York, N. Y.
Mullin, G. E., Jr., Gen. Elec. Co., Indianapolis, Ind.
Mullin, LeR. A., Syracuse Univ., Syracuse, N. Y.
Nellis, E. J., Brooklyn Edison Co., Brooklyn, N. Y.
Noell, J. J. (Member), T. V. A., Knoxville, Tenn.
O'Hara, E., Union Gas & Elec. Co., Cincinnati, Ohio.
Pettibone, G. H., Gen. Elec. Co., Schenectady, N. Y.
Phillips, H. H., Osborne Elec. Corp., Niagara Falls, N. Y.
Powers, W. H., 337 So. Main St., Ann Arbor, Mich.
Ranhofer, E. J., N. Y. Hospital, New York, N. Y.
Ransom, C. W., Gen. Elec. Co., Pittsfield, Mass.
Reynolds, F. J., N. Y. Hospital, New York, N. Y.
Rohats, N., Gen. Elec. Co., Schenectady, N. Y.
Sashoff, S. P., Univ. of Fla., Gainesville.
Shaw, O. J. (Member), Municipal Construction & Finance Co., Lincoln, Neb.
Shelby, R. E., Nat. Broadcasting Co., Inc., New York, N. Y.
Sherwood, E. T., Globe Union Mfg. Co., Milwaukee, Wis.
Sinks, A. T., Gen. Elec. Co., Lynn, Mass.
Smith, L. M. (Member), Ala. Pwr. Co., Birmingham.
Snediker, J. B. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Stevenson, G. L., Detroit Edison Co., Mich.
Towers, R. C., Brooklyn Edison Co., Brooklyn, N. Y.
Tulloch, D. F., Edison Elec. Illum. Co. of Boston, Mass.
Underwood, L. T., Elec. Lt. Dept., Little Valley, N. Y.
Van Hamel, T. A., Gibbs & Hill, New York, N. Y.
Watts, T. O., E. L. Ruddy Co. Ltd., Toronto, Ont., Can.
Winther, R. O., Signal Elec. Mfg. Co., Menominee, Mich.
Wood, M. B., Chase Shawmutt Co., Newburyport, Mass.
Wright, C. P., Univ. of Manitoba, Can.
Wright, J. D. (Member), Gen. Elec. Co., Schenectady, N. Y.
Yeary, O. N., Texas Elec. Serv. Co., Ft. Worth.

96 Domestic

Foreign

Mita, N., Electrotechnical Laboratory, Ministry of Comm., Tokyo, Japan.
Romer, M. J., Rochussenstraat 200, Rotterdam, Holland.
Sirajuddin, A. W., Pub. Works Dept., Amritsar, India.

3 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Chiofalo, J., 203 Graham Ave., Brooklyn, N. Y.
Crite, Mitchel, 32 E. 126th St., New York, N. Y.
Ghosh, K. C., c/o Compagnia Generale Di Elettricita, 34 Via Borgognone, Milan, Italy.
Golikoff, A., Main P. O. Gen. Del., Moscow, U. S. S. R.
Kimball, Gordon S., 154 Elmer Ave., Schenectady, N. Y.
Nelson, Charles J., 1515 N. Lotus Ave., Chicago, Ill.
Rozelle, P. M., 2018 Chestnut St., Harrisburg, Pa.
Soskin, Samuel B., 1141 S. Central Park, Chicago, Ill.
Spiegel, William F., 7 Stegman Court, Jersey City, N. J.
Vance, Paul E., c/o Marietta Mfg. Co., Point Pleasant, W. Va.

10 Addresses Wanted

1935 Index—Electrical Engineering and Transactions

This multientry annual reference index covers comprehensively the entire text content of the 12 issues of ELECTRICAL ENGINEERING published during 1935 and of the identical content of the 1935 A.I.E.E. TRANSACTIONS, volume 54.

Discussions have received particular attention and a special effort has been made to provide effective correlation between references to technical papers and to all published discussions of those papers. In this connection it is of importance to note that discussions of many technical papers published during the latter half of 1934 were published in the early part of 1935, and hence appear in this current index.

Likewise, many discussions of the later 1935 papers will be published early in 1936, and consequently will not be found among the references contained in this current index.

For convenience in use, this index is subdivided into the following general divisions:

1. Technical subjects.
2. Authors, including the writers of discussions.
3. News items pertaining to Institute activities.
4. News items of a general nature.
5. Biographical (personal and obituary) items.

Division I—Technical Subject Index

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Note—An asterisk (*) before a page number denotes publication of individual's picture on that page.

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MEETINGS, NATIONAL:

Division IV—News of Non-Institute Activities

Division V—Biographical Index

Includes All Personal and Obituary Items.

NOTE—An asterisk (*) before a page number denotes publication of individual's picture on that page.

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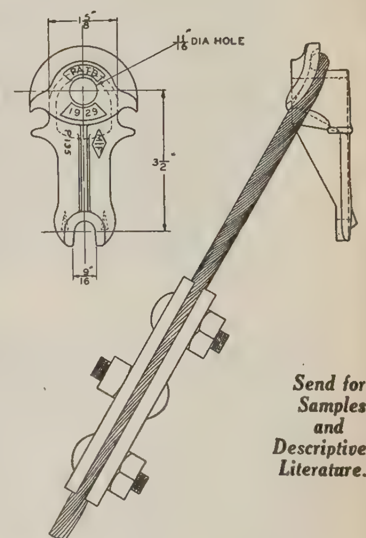

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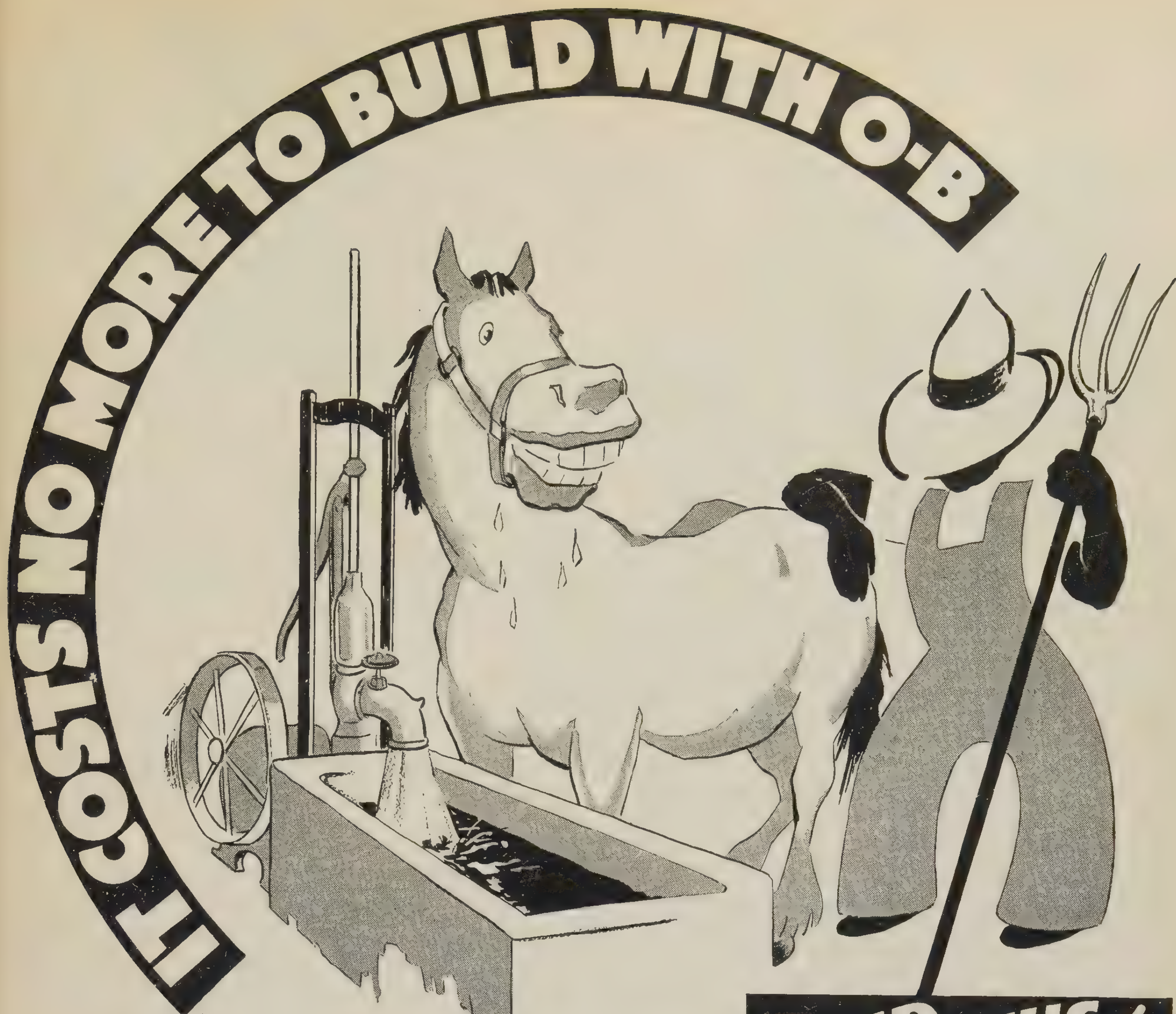
Pole Mounts for new and salvage construction and wedged Band Pole Stubbing Clamps also play their part in maintenance of low-cost rural lines.

MALLEABLE IRON FITTINGS COMPANY
Pole Hardware Dept. [Factory and New England Sales Office] **Branford, Connecticut**
New York Sales Office: Thirty Church Street
Canadian Mfg. Distributer:
LINE & CABLE ACCESSORIES, Ltd., Toronto



WATER at the throw of a switch! A hundred and one farm-tasks made easier and surer by the use of electricity. Attractive rates are the inducement—low construction costs one of the means. But low-cost farm-lines need not mean poorly constructed lines. For instance, O-B materials can be used at no increased cost. Price for price, item for item, O-B quality is no dearer.

Remember, it costs no more to BUILD WITH O-B

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A.I.E.E. STANDARDS

The Standards of the American Institute of Electrical Engineers now consists of forty-three sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.

The Standards available are listed opposite, together with prices. A discount of 50% is allowed to Institute members. Such discount is not applicable on extra copies unless ordered for other members. Numbers of the Standards Sections should be given when ordering.

SECTIONS IN PREPARATION

Eight such sections are now available in report form for purpose of criticism, and copies will be sent without charge upon request, with the exception of No. 2 and C50, for which there is a non-member charge of $1.00 and 50 cents, respectively, with usual 50% discount to members. These sections are as follows:

No. 2	(Aug. 1932) Electrical Definitions.	$1.00
6	Mercury Arc Rectifiers.	
23	Relays.	
28	Lightning Arresters.	
40	Electrical Recording Instruments.	
*C50	Rotating Electrical Machinery.	50 cents
—	Test Code for Transformers.	
—	Test Code for Synchronous Machines.	
—	Test Code for Polyphase Induction Machines	

** Report on proposed American Standard. Will eventually replace Standards Nos. 5, 7, 8, 9 and 10.*

A binder (illustrated above) for standards is available. The stiff covers are finished in a long wearing material, resembling leather, suitably lettered in gold. Price $1.75 net.

[Figures in Parentheses Give Dates of Latest Editions.]

No. 1	General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery (4-25)	$0.20
4	Measurement of Test Voltage in Dielectric Tests (5-28)	.30
5	D-C Generators and Motors and D-C Commutator Machines in General (7-25)	.40
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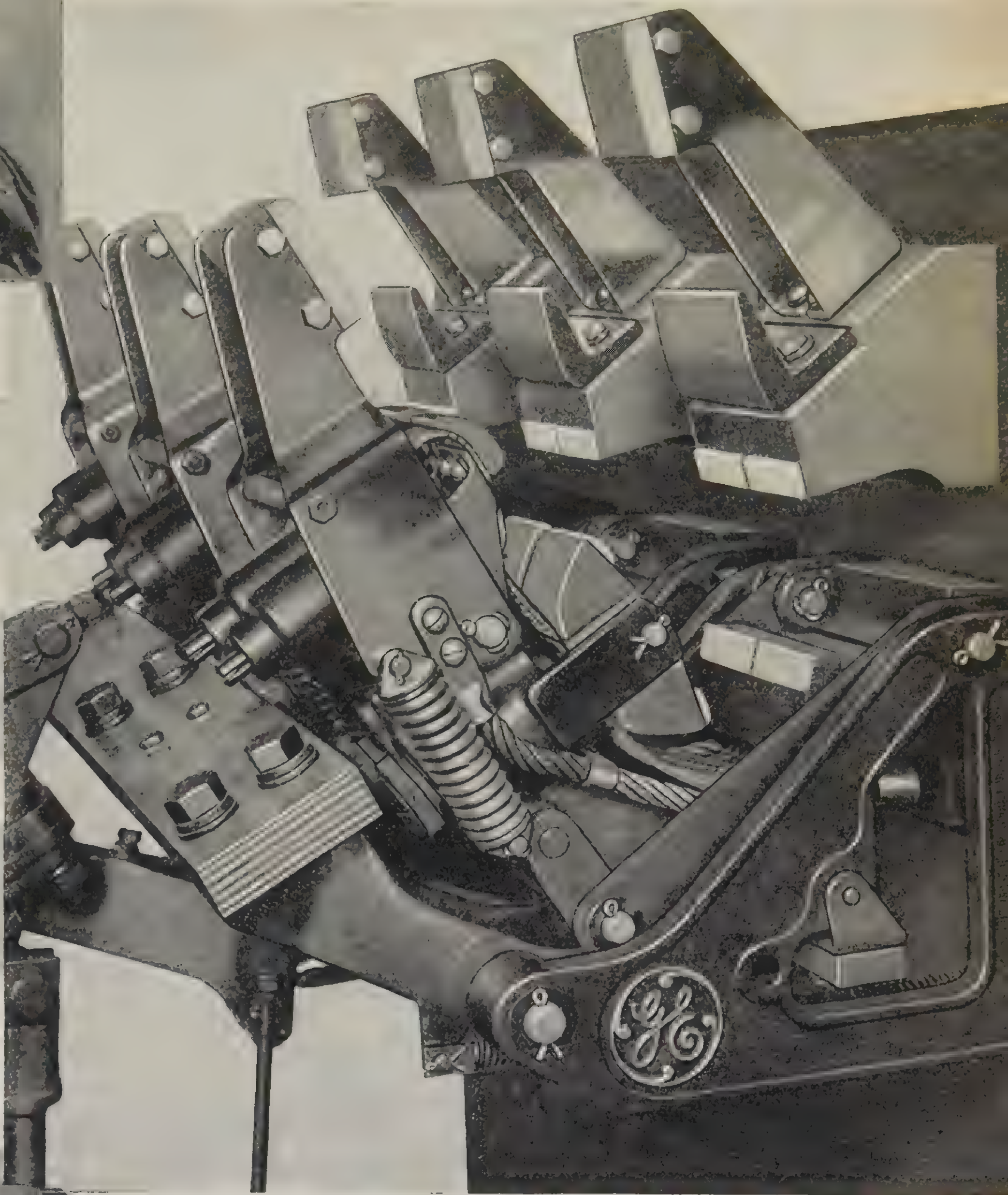

SOLID SILVER main contacts give long service — they stand up under repeated operation.

SOLID SILVER main contacts eliminate high-resistance oxidation — reduce heating and assure accurate operation.

SOLID SILVER main contacts require less cleaning—less maintenance.

Complete lines of G-E air circuit breakers are available for all services, both a-c and d-c

WHEN you specify General Electric, the air circuit breaker with the solid silver main contacts, you get:

Better protection, lower maintenance—because the main contacts are solid silver—bars of silver welded to the copper.

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Savings in space—because the designs are extremely compact.

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Safety—Accuracy—Durability

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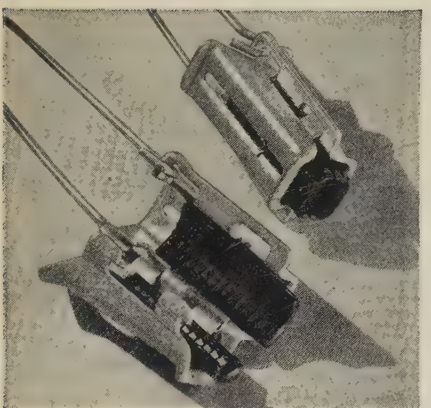
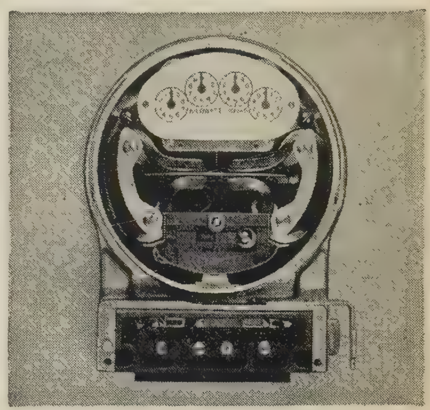


House Brackets. Heavy responsibility rests on the wedges employed in this device. Exposed to constant physical strain and extremes of weather, they must retain unfailing insulation value. After extensive research, Hubbard & Co. adopted Bakelite Molded as the superior material for wedges in the Hubbard wedge-grip bracket.

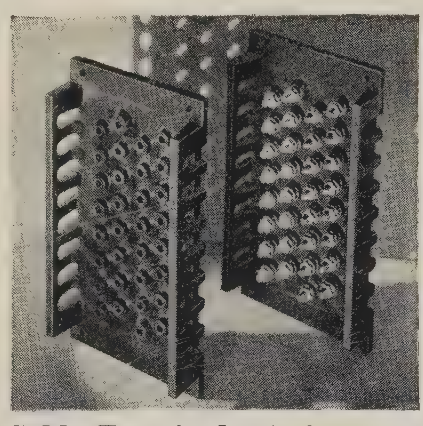
THROUGHOUT the electrical industry, Bakelite Molded is employed for a constantly increasing number of applications where the major requirements are permanently high insulation value, precision of form, dependable operation, and long, faithful service under trying conditions.

The examples illustrated offer but slight indication of the widely varied usefulness of this versatile modern material. For information on other present applications and specific properties of Bakelite Molded, engineers and manufacturers of electrical equipment and devices are invited to write for our Booklet 33M, "Bakelite Molded".

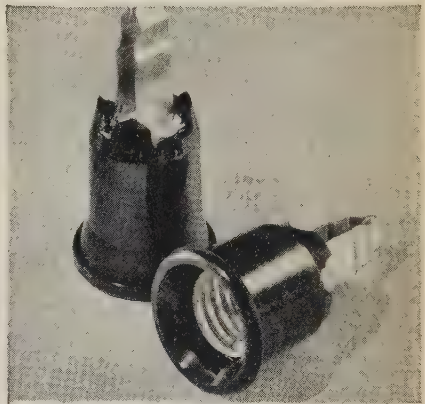


Watthour Meter. Four leading meter manufacturers have adopted interchangeable terminal blocks for their watthour meters. These blocks require great accuracy of dimension, high insulation value, strength, and resistance to extreme atmospheric conditions. Bakelite Molded was the unanimous choice of the engineers because it fulfilled every requirement.

Fuse Cut-Out. The heavy Bakelite Molded door of this L.M. disconnecting fuse cut-out gives positive protection against shocks during inspections or renewals. Besides offering safety, Bakelite Molded does not deteriorate, and retains its electrical and physical properties for an indefinite length of time.



Cable Terminals. Cook Electric Co., who pioneered on the use of Bakelite Molded for insulation blocks of pole cable terminals, state: "The ability of Bakelite Molded to withstand the elements; its high tensile strength, high insulation value, plus low absorption properties, justified our adopting it five years ago."



Mogul Sockets. In forming the heavy shells of these lamp sockets from Bakelite Molded, the Line Material Company has realized, not only important electrical advantages, but also practical insurance against deterioration and failure of the sockets under any climatic or atmospheric conditions.

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1910 — SILVER ANNIVERSARY — 1935

Employment Bulletin

Engineering Societies Employment Service

MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the three offices will bring full information.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3 per quarter or $10 per annum, payable in advance.

In the interest of effective service, it is essential that members using the employment service keep the bureau office serving them advised at reasonable intervals concerning their availability for employment, concerning any change in status, and immediately upon acceptance of any employment.

Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York Office.

•

Men Available

E.E., age 36, M.I.T. grad. Exper constr, oprn, appraisal, util and factories; also eqpt des and factory research. Broad engg and scientific background. Salary secondary to real opportunity. C-9749.

E.E., Univ grad, $6^1/_2$ yrs des, engg, constr hydroelec, steam pwr plants, substations, transm, ry electrification; 6 yrs engg automatic switchgear, supervisory, telemetering eqpt pwr, ltg, indus, ry service. Speaks German, Spanish. B-7938.

GRAD E.E., 35; 10 yrs exper pub util includes des, constr, oprn of transm, distr systems, investigations, economic studies, valuation, rate investigation, latest lightning protection methods, preparing estimates, specifications, contracts. C-3564.

TRANSM LINE, SUBSTATION DES ENGR, E.E. grad, 1929, single, 29; 4 yrs des substations; $1^1/_2$ yrs des single and H-frame wood pole; one yr oprtg elec induction motors, control eqpt. C-5967.

E.E., B.S., 1935, Newark Col of Engg, single. Desires any pos in elec field leading to advancement. Exper: Radio servicing, machine shop, tech report writing. Location, NYC or NJ. D-4443.

E.E., B.S., Univ of Kansas, 1935, single, 24. Pwr option. Desires work in engg field. Location immaterial. Available immed. D-4420.

M.S. in E.E. and grad yr in business administration, both at M I T. One yr Gen Elec test course. Mgmt exper. Retail store exper. Age 26. D-1538.

E.E., B.S., Va Poly Inst 1933. Major: pwr machy. Minor: auto engg, tech report writing, journalism. Pi Delta Epsilon. Exper: Civil Engg, teaching, draftg. Married. Hard worker. D-2426.

E.E., B.S., 1935, Tau Beta Pi, single, 22. Desires exper in some field, preferably pwr engg or des. Salary secondary if advancement is possible. Location immaterial. D-4483-5460-Chicago.

E.E., 37, married, 16 yrs exper oprtg pwr systems, des pwr plants, indus. Last 10 yrs elec des engr in charge E.E. Univ Darmstadt. Location, anywhere. D-4466.

DEVPMT ENGR, des, B.S., '25, married; 7 yrs lab research for prod control, 3 yrs des fractional hp motors, E.E. 1934 in connection with special work on small motors. Good ref. D-2165.

E.E., 1928, single; 4 yrs pub util exper includes lab and pwr plant testg, underground transm lines and distr systems; maintenance and consumers' service specifications. D-4277.

SALES ENGR or EXEC, E.E. deg, 15 successful yrs in radio and elec indus selling, sales promotion, sales mgmt for nationally known mfrs. Excellent training in business, advertising, publicity. East. D-4330.

ASSOC, ASST PROF OF E.E., 37, BS AND MS IN E.E.; 5 yrs teaching leading tech sch; 6 yrs personnel work nat tech corp including selection, training of tech grad. C-8967.

E.E., B.S., 1930, single, 29; 3 yrs pwr transformer des. Good theoretical training and practical knowledge of radio. Desires pos in radio or tube mfr's lab. Location immaterial. D-462.

PRACTICAL E.E., 49; 25 yrs exper in constr oprn and des. Can work in office as engr or checker or on job as asst supt, field engr or foreman. D-4063.

E.E., B.S., 1934, N.Y.U., honor student. Desires engg exper in pos with future. Good lab technician. Familiar with business methods, labor mgmt. Secretary for exec of tech co. Excellent ref. D-4170.

ENGINEERING SOCIETIES EMPLOYMENT SERVICE

NEW YORK 31 W. 39th St. SAN FRANCISCO 57 Post St. CHICAGO 211 W. Wacker Dr.

Far Speaking TOWERS

Center: 230-foot radio tower terminating in a single mast, fabricated and erected by American Bridge Company in northern Wisconsin.

Right: One of two 200-foot A.B.C.—constructed radio towers at Fort Brown, Texas, shown completed and with antennae in place.

Left: Twelve specially designed 400-foot radio towers with 150-foot cross arms, designed, fabricated and erected by American Bridge Company, for the Radio Corporation of America at Rocky Point, L. I.

RADIO TOWERS—singly or in stands of a dozen or more, high, strong, of balanced construction and nicely adapted to their intended use—have been a specialty of the tower department of American Bridge Company for many years. A technically trained and widely experienced personnel commands resource in design to meet all conditions that may be involved for any broadcasting project. Modern fabricating and erecting equipment and ample facilities of every kind required, assure a finished structure economically built as well as of adequate strength.

The diversified knowledge of American Bridge Company technicians concerning towers for other uses, from the simplest type of transmission tower to the most complicated sub-station, is always at command to assist in the study of special difficulties or requirements.

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THE GIFT OF FRIENDSHIP

THERE is a priceless gift within reach of every one—the gift of friendship.

Of all the services of the telephone there is none more important than this—helping you to make friends and to keep them.

When people are in trouble, you go to them quickly by telephone. The telephone carries your good wishes on birthdays, weddings and anniversaries. Arranges a golf game or gets a fourth for bridge. Invites a business acquaintance to your home for dinner, and advises "home" that he is coming. Congratulates a youngster on his work at school. Thanks a neighbor or asks about the baby. Renews old times—shares confidences—plans for the future.

Thus the bonds of friendship are formed and strengthened. Greater happiness comes into the widening circle of your life. Some one, somewhere, says sincerely—"It was nice of you to call." This day, a voice-visit by telephone may bring reassurance to some friend who is wondering how you are.

More and more are people turning to Long Distance to carry friendly voices across the miles. They like its speed, clarity, intimacy and low cost—especially after 7 P.M., when calls by number to most points cost about 40% less than in the daytime.

BELL TELEPHONE SYSTEM

ADVERTISERS